

# Energy Research in Developing Countries



**ENERGY RESEARCH IN  
DEVELOPING COUNTRIES**

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Compiled by  
Stephen Graham

**International Development Research Centre**

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# Introduction

David B. Brooks<sup>1</sup>

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The Energy Research Group (ERG) was a joint project of the International Development Research Centre and the United Nations University. Conceived in 1981, at the same time as the United Nations Conference on New and Renewable Forms of Energy, ERG consisted of a panel of 11 scientists from as many developing countries. Because the bulk of energy research was both funded by and carried out in developed countries, ERG chose to suggest how to focus that research more directly on the needs and priorities of developing countries and, if possible, how to shift some energy research to those countries.

The broad conclusions of ERG were published in 1986 (ERG 1986) and fulfilled the two main parts of its mandate, which were to

- Recommend priorities in the conduct and use of energy-related research and present its findings to decision-makers, researchers, and other interested parties, and
- Recommend ways to determine the allocation of resources for energy-related research and ways in which this allocation could be improved, both nationally and internationally.

The preface to *Energy Research: Directions and Issues for Developing Countries* (ERG 1986) provides a history of the project and a summary of its approach and conclusions.

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<sup>1</sup> Director, Environmental Policy Program, Environment and Natural Resources Division, International Development Research Centre, Ottawa, ON, Canada.



The two main parts of the ERG mandate were supported by several other elements, which allowed ERG to

- Carry out a thorough review of energy-related research and technology relevant to developing countries,
- Survey the existing and likely capability in developing countries to conduct, finance, diffuse, and use energy-related research and development, and
- Survey energy-related research and technology in developed countries, its relevance to developing countries, the terms under which access was available, and the ways of using this information for the greatest benefit of developing countries.

These three elements of the ERG mandate were essential to its main work. However, they required knowledge of such a wide range of technologies, geographies, and issues that the 11 members of ERG could not hope to know all or even most of what was required. To fulfill these three supporting elements of the ERG mandate, over 100 state-of-the-art reviews were commissioned. The list of authors reads like a "Who's Who" of energy analysis in the 1980s. A full list of these reviews appears in the Bibliography. Copies of the typescript versions of all reviews are housed in a special collection at the IDRC Library.

The final element of the ERG mandate was to

- Disseminate the views of the Group, invite informed opinion, and provoke discussion on the energy-related issues facing developing countries.

This part of the mandate was fulfilled, in part, by the publication of the main ERG report (ERG 1986). As well, 14 additional volumes were published under the general editorship of Ashok V. Desai, a member and the coordinator of ERG. These volumes were organized by subject matter (according to commodity, region, or issue) and contained information from 60 of the original 103 commissioned reviews. In a number of cases, several reviews were combined into a single paper.

All studies were subject to peer review by two, or in some cases three, energy experts. Comments were also received from staff at the World Bank Energy Policy Program and at the Science Policy

Research Unit at Sussex University. In principle, those studies selected for publication were considered by the reviewers and by the ERG panel as methodologically sound and as a contribution to their field. However, some subject areas (notably environment and institutions) were not included.

This book is a one-volume summary of the 14 volumes of research reviews. These reviews, despite their gaps, present a reasonably complete picture of the relevance of energy knowledge to developing countries from the perspectives of the natural and social sciences in the mid-1980s. As such, the book completes the final element of the ERG mandate.

Each chapter in this summary volume represents one of the original 14 volumes. Within each chapter, the main points and conclusions of each review are summarized. The summaries were prepared in 1992 and 1993 by a number of energy specialists under the general direction of Stephen Graham, a consultant to the ERG. They were subsequently edited to their final format by Michael Graham.

Energy specialists may wish to explore the full studies; however, this book should be useful to a wide audience. No attempt is made to summarize the main ERG report, which stands on its own.

## **Relevance Today**

*Energy Research: Directions and Issues for Developing Countries* was published in 1986. However, for a number of reasons, largely related to communication with globally dispersed authors and copublishers, publication of the 14 commodity-, region-, and issue-oriented volumes was delayed. When they appeared in 1990, interest in the issue of energy had waned considerably, particularly in the North. The issues that had led to the oil-generated energy crisis of 1973 (and the less widely recognized but more traumatic crisis of 1978–1979) were no longer as pressing because energy supplies had grown and sources had become more diversified.

Economic forces also pushed energy to an issue of secondary importance. Income growth lagged behind the optimistic expectations of the early 1980s (throughout the world but notably in devel-

oping countries), and, as a result, growth in demand for commercial energy lagged. As well, because large blocks of capital were no longer as readily available, projections that energy investments in developing countries would double from 2 to 4% of gross domestic product (GDP) (World Bank 1983) were not fulfilled. Certainly, energy prices never again reached the levels of 1979. Today, most forms of energy cost little more in real (inflation-free) dollars than they did in the 1960s.

However, these reviews are still relevant because of

- The perspective they offer on the history of energy-in-development as an issue,
- The information they contain on energy technologies and options, and
- The gaps that are now evident in both perspective and content.

This threefold relevance is, in some ways, more evident in this single summary volume than it was in either the main report or the 14 separate volumes.

## **Perspective**

The main ERG report, the 54 reviews published in the 14 volumes, and the remaining unpublished studies represent an important stage in the history of energy analysis. They indicate how energy-in-development was seen by competent and involved scientists from developing countries during the mid-1980s. Notable is the broad shift in perspective that is represented by the three explicit premises on which the ERG study was conducted and the reviews were commissioned (ERG 1986, pp. 1–3). These premises were that

- Energy research must be related to research on the entire economy and society,
- Energy sources must be studied in the context of the demand for them, and
- Energy saving is as important as energy production.

ERG deserves enormous credit for basing its work on these premises, which are, if anything, even more important today than they were when the group was active. The fact that the collection of reviews does not fully live up to the challenge of these premises —

energy saving received less attention than energy production, and social issues received much less attention than technical issues — is less relevant than the cast they put over the whole body of work. The work of ERG represented a significant advance over most of what had come before.

The ERG program of work was designed in the early 1980s, at a time when conventional wisdom held that large increases in energy capacity would be needed to power development in the South. Therefore, its perspective on the energy problematique was almost radical. A similar perspective was also emerging in the industrial world, where more and more studies were, implicitly or explicitly, based on the same three premises. However, with the partial exception of “soft energy path” analyses,<sup>2</sup> these studies fell equally short.

## **Content**

Research funding, and to a lesser extent research interest, follows political and economic trends. Because interest in energy as an issue waned during the latter half of the 1980s, funding and interest in energy research slipped. Advances continued to be made, particularly in end-use efficiency and in some new supply technologies (for example, fuel cells). However, for the most part, the reviews commissioned by ERG have stood up remarkably well over the last decade. If they were offered for publication today, they would require little revision to provide an accurate reflection of current methods to assess options for the use of energy research in development planning. In short, the ERG work provides sensible, clear information on such topics as patterns of energy use in developing countries, alternative liquid fuels, and energy in Africa.

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<sup>2</sup> Soft path studies corrected the supply-side bias but gave only a little more attention to social issues. “Soft energy path” analysis was an attempt to approach energy from the demand side and from a futures rather than a projection perspective. The original work was by Lovins (1976), and examples of this type of analysis for Canada can be found in Bott et al. (1983) and for developing countries in Goldemberg et al. (1988).

## Gaps

Despite the breadth of perspective, and the deliberate look for alternatives, some aspects of the energy–development discussion are missing from the research reviews and, to a lesser extent, from the main ERG report. The two gaps that deserve specific attention are energy and environment, and energy and politics.

Only two of the studies commissioned by ERG could be considered environmental. One was by El-Sayed (*Health and Environmental Impacts of Energy Systems*), and the other was by Smith and Ramakrishna (*Traditional Fuels and Health: Social, Economic, and Technical Links*); neither was published. Although some of the other studies did refer to environmental issues, they did so only in passing and without any overall perspective on the nature or extent of environmental impacts resulting from energy use. Much better work on energy and environment was available than is reflected in the research reviews, although little of it was specifically focused on developing countries (for example, Holdren et al. 1980; UNDP 1985).

In the main ERG report, environment does get a fair bit of attention — certainly more than would be expected from its comparative neglect in the research reviews. One must surmise that, in the late stages of their work, the members of ERG realized that

- Environment was a more critical development issue than had been recognized at the start, and
- Energy production and use were among the most serious sources of environmental degradation at the local, regional, and global levels and were closely tied to development problems.

Perhaps, too, the notion that “environment” was more a Northern than a Southern issue had begun to lose the credibility that it unfortunately held for some time after the United Nations conference in Stockholm in 1972.

If environment was neglected as an issue in the ERG reviews, it would appear that politics was deliberately avoided. With the partial exception of some references to women’s issues, fuelwood and

nuclear proliferation, the role of energy availability as a form of empowerment at the local level was almost totally ignored. Also ignored was the role of large and typically transnational corporations in energy supply at the global level.

There was no discussion of various collective approaches to energy supply and delivery (for example, village-scale electrical cooperatives). Absent, too, were references to workers' actions aimed at the oil industry in Nigeria (for example, Turner 1990) as well as reviews of the ways in which both private and public energy corporations organize to protect their interests. There was also no discussion of the fact that alternative transportation fuels imply not merely different energy systems but also a different distribution of economic gains and environmental losses. In a few cases, political aspects were emphasized. However, these reviews by Peter Hayes, Wereko-Brobby, and a few other analysts were neither published nor cited in the main ERG report.

In the selection of reviews to publish, and in the editing, almost all political discussion was eliminated (for a perspective on Hayes' political views, see Hayes (1981); Wereko-Brobby's views can be found in a number of reports he prepared as Director of Ghana's National Energy Board, for example, Wereko-Brobby (1988)). In contrast to the environment, politics received no greater attention in the main ERG report. It was rather as if the world was seen as a very orderly place, where the only difference between rich and poor nations was that the former were rich and the latter poor — a world in which the politics that linked energy and development could be left safely to nongovernmental organizations (typical examples involving electricity include Goldemberg et al. 1988; Butera 1989; Foley 1990; Geller 1991).

With the benefit of hindsight and of the considerable shift in perspective after the publication of the Brundtland Report (WCED 1987), it is now apparent that the absence of environmental and political aspects weakened the impact of ERG's work. More broadly, it reflects the Group's failure to recognize a still only partially emerging new development paradigm. As Gus Speth said in an

address to UNDP staff after he assumed his post as Administrator in mid-1993:

What is this new paradigm? ...it says that development that does not improve the lives of the great mass of the poor has no soul, that development that impoverishes the environment has no vision. It says that development does not occur in a political vacuum but depends both on effective governance and also on the empowerment of the many communities in civil society to participate in the decisions that affect their lives.

These were just the areas ignored or downplayed by ERG in what was likely an attempt to constrain the energy–development debate within reasonable bounds and to ensure that South–North consensus would be as strong as possible. The goal was to emphasize the potential benefits of cooperation in energy research, not to focus on the political conflicts implicit in their patterns of development.

Nonetheless, this one-volume overview of the ERG research reviews brings out the merits of the 14 separate volumes. Despite the caveats, the effort represented by the sum of the main ERG report and the reviews was, and is, impressive. For the most part, the work stands up well to inspection nearly a decade after most of the analyses were completed. This is certainly a tribute to the individual researchers, the members of ERG, and the secretariat that managed the process for 4 years.

## Volume 1

# Patterns of Energy Use in Developing Countries

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*Volume editor: M. Ali Kettani*



# **Energy Consumption Patterns and Their Implications for Energy Planning**

*Joy Dunkerley,  
with the assistance of Michele Gottlieb*

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## **Overview**

This paper uses an energy balance, which is an accounting system that defines energy flows at the national level, to review patterns of energy consumption. There are four demand sectors (industry, transportation, household, and commercial) and a nonenergy or petrochemical feedstock sector. Energy flows are influenced by the primary factors that affect the demand sectors and by energy transformation processes. Energy conservation and fuel substitution can further influence the energy balance.

## **Analysis**

### **The Energy Balance**

Data on energy supply-demand from the United Nations, the International Energy Agency, and the Latin American Energy Agency for 55 countries provide useful comparative information in an energy balance format. This format produces energy information on total consumption of each primary fuel, transformation of primary to secondary energy, and energy demand for four sectors. Variations in

the energy balance formats, the treatment of electrical conversion, and the units of measurement can lead to different methodologies. Final energy demand and useful energy, which incorporate the concept of the efficiency of conversion and the notion of energy embodied in trade commodities (particularly steel), are conceptually important to understanding the methodology.

## **The Sectoral Energy Demand**

Energy intensity, or energy (E) consumed per unit of gross national product (GNP), appears to be higher in developing countries. However, when a correction is made for "exchange rate bias," which understates the level of income in developing countries, the E to GNP ratios are comparable (with some variations) with those of developed countries.

There are considerable differences in the structure of energy demand among low-, middle-, and high-income countries. In low-income countries, the highest demand sector is the household because the largest energy use is cooking and the devices are inefficient. As incomes rise, energy consumption for cooking may decrease because more efficient cooking devices and more efficient fuels are used. Fuel subsidies, commercialization of fuelwood, and access to modern fuels affect the energy demand of the household sector.

Industrial energy use is correlated to the size of the industrial sector, the types of industry, and the energy intensity of the individual processes used by industrial plants (for example, open-hearth burners or basic oxygen burners for steel, and either the wet or dry process for cement). The most important factor in determining industrial energy demand is the type of industry. India and Jamaica are examples of heavy-industry countries with large industrial energy demands. The mix of fuels used in the sector varies by industry type because the agroindustry may continue to use traditional fuels, whereas heavy industry requires modern fuels.

The transportation sector has the widest variation in energy demand within developing countries. Most of this variation can be

explained by income or GNP because economic development requires or causes wider transportation networks for goods, and higher income causes a shift to a higher intensity transportation mode (for example, cars) for personal travel. Country size and geographical conditions, as well as government policies, regulations, and taxes, also help determine the energy demand in the transportation sector.

The transformation sector, principally the generation and distribution of electricity, becomes a large consumer of energy in middle-income countries when the requirement for electricity grows, principally in the industrial sector. In turn, electricity pricing and other government policies (for example, rural electrification) are the prime determinants of electricity demand.

### **The Potential for Conservation and Fuel Substitution by Sector**

There is limited possibility for petroleum substitution in the transportation sector because rail transportation is appropriate only for high-volume routes. However, liquefied coal, ethanol, and methanol may be substitutes that require limited costs for vehicle conversion. Improving the efficiency of each mode that uses petroleum products is a more feasible option for petroleum conservation. Conservation measures include improved public transit and traffic flows in cities and the use of taxes to reduce demand for inefficient cars. The industrial sector provides the greatest possibility for substitution of fuels, but it requires a large capital investment. However, correct pricing policy and training in industrial management for energy “housekeeping” could also help conserve energy. In the household sector, access to free fuelwood and resistance to new cooking devices retard improved energy efficiency. Subsidies for kerosene use worsen the problem because the subsidy is abused by the middle class. However, this demand sector has large substitution and conservation potential.

## **Suggestions for Further Research**

Research is needed to analyze

- Sectoral energy demand (with particular attention to the impact of price),
- Possibilities for interfuel substitution,
- The determinants of biomass use and its substitution potential,
- The impact of development strategies on energy demand,
- The relationship between economic development and transportation services,
- The determinants of energy demand in households and the substitution potential of fuels in this sector, and
- The potential to substitute other fuels for oil and other factors of production, such as labour, for energy.

# **Energy Use in Industry**

*B.G. Tunnah*

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## **Overview**

This paper reviews the major processes that consume energy in an energy-intensive industry and focuses on thermal processes (for example, combustion, drying, and distillation). An energy audit, which measures and monitors energy use, can be used by industry. Inefficiency in energy use can be addressed by conservation techniques and government policies. The conservation programs of six developing countries demonstrate the effectiveness of these approaches.

## **Analysis**

The three industrial energy processes are thermal, mechanical, and chemical. The highest proportion of industrial energy is used in thermal processes (for example, combustion, steam generation and distribution, heat exchange, electricity generation, evaporation, and melting). In the conservation of thermal energy it is useful to understand the terminology (for example, complete combustion, coefficient of heat transfer, boiler efficiency, and distillation towers). Other energy processes include gas compression, space conditioning, grinding, refrigeration, and electrolysis. Examples of typical energy intensities in the industrial sector are 2–6 MJ/L of beer, 3.3 MJ/kg of sugarcane, 5.6 GJ/t of wet cement, and 4 GJ/t of bricks.

## Energy Audit

An energy audit is the first step to reducing the energy intensity of an industry. There are nine steps to planning and conducting an energy audit. Measurements of energy use focus on the efficiency of boilers and heat exchangers and on heat loss from pipes and vessels. Measurements can be made of energy use in dryers and distillation towers.

Common areas of inefficiency often include

- Energy management — lack of commitment by top management, lack of proper instrumentation, lack of accurate reporting, and lack of acceptable standards of plant housekeeping,
- Combustion processes — poor instrumentation, lack of air control, and poor maintenance,
- Heat transfer — failure to monitor performance, poor or inadequate insulation, and poor maintenance,
- Steam generation — poor water treatment and inefficient or leaking steam traps,
- Drying — poor control over product moisture and moisture of wet feed and poor insulation, and
- Evaporation — poor insulation and poor control of moisture.

Major differences in energy intensity within the same industry can be explained by the different processes used and by the age and size of the equipment. Management skill is one of the most critical elements.

Some constraints to improving energy efficiency are

- A lack of understanding of the equipment and techniques available,
- A lack of proven technology,
- A lack of capital for investment,
- Institutional constraints (for example, incorrect energy prices and price uncertainty), and
- A lack of decision-making and no commitment by management.

## **Energy Conservation Principles and Programs**

A principal focus of any conservation program should be the recovery and use of waste heat. In any conservation program it is important to determine the potential heat sources, establish the potential quantities of heat that can be recovered, determine the overall costs (including investment and maintenance), and balance these costs with energy savings. Fuel substitution may also produce cost savings and should be investigated.

In the early 1980s, conservation programs for industrial energy were undertaken in China, the Philippines, Sri Lanka, Sudan, Tunisia, and Uruguay. These programs provided useful demonstrations, although most only estimated potential savings and trained plant engineers in energy management.

The most important elements of any program of energy management are the commitment, communication, leadership, and expertise of management and the appointment of an energy manager to coordinate record-keeping, give technical advice, identify areas of waste, prioritize plant activities, and advise senior management.

Industrial activity must be supported by government policy on energy management. This policy should include sending correct price signals on energy and modifying market forces to achieve other objectives. It should also include regulations on mandatory equipment standards and energy reporting, incentives and subsidies for efficient equipment, demonstration projects and training, energy audits, and information dissemination.

## **Suggestions for Further Research**

Applied research may present new opportunities for energy efficiency in multifuel burners, small-scale coal gasifiers, small-scale coal boilers, low-cost plate heat exchangers, low-cost heat pumps, and small-scale wood and biomass residue gasifiers.

# **Energy-Intensive Materials**

*Alan M. Strout*

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## **Overview**

This paper reviews the methods used to determine the energy intensity of materials and explores the importance of energy-intensive materials (EIMs) to overall energy demand. The relationship of EIMs to income or gross domestic product (GDP) is explored, and current EIM production sites are discussed. The theoretical impact of increases in energy price on EIM prices is calculated, and the potential for reducing energy intensity is discussed. The future of developing countries in the production of specific EIMs is explored.

## **Analysis**

Discussion of the energy intensity of materials (measured as energy input per unit weight of commodity) has focused on a small number of commodities. However, a more accurate and complete view of energy intensity can be gathered from an input-output approach, which includes the indirect energy embodied in transportation, the capital equipment of production, and measurements or coefficients per dollar of output. Some studies also include the input of solar energy to production. The Energy Research Group has produced coefficients of energy intensity for 357 input-output sectors. Several paper and food products are among the most energy-intensive commodities, all of which consume more than 73.8 MJ/USD of output.



Industrial energy accounts for a significant share of all energy. The 17 most energy-intensive materials required just under 26.9% of all the world's energy from 1978 to 1980. Technological improvements may have reduced this figure, but new EIMs have been added. In terms of embodied energy in traded commodities, this may add 50% to the energy recorded in exports. About 50% of this embodied energy is in the most energy-intensive commodities.

Developing countries were low producers of EIMs. However, middle-income developing countries produce more EIMs than industrialized countries. In general, 52 countries account for 98% of the world's production of 10 EIMs and 95% of their consumption. Chile, Greece, Peru, and Spain were among the middle-level net exporters.

### **EIMs, GDP, and Increases in the Price of Energy**

Consumption and production of EIMs grow until per capita GDP reaches about 2 000 USD (1970). The contribution of EIM to GDP then declines because of growth in the service sector, which is less energy intensive. Consumption of EIMs usually exceeds production in low-income countries as the demand for manufactured goods increases. The rate of consumption of EIMs decreases more quickly than the rate of production when per capita GDP is higher than 2 000 USD.

Based on the increases in the price of energy from 1976 to 1980, a 70% increase in fuel cost led to only a 6% increase in the price of EIMs (relative to an average index of commodity prices). An economy-wide model was constructed for the UN in the 1970s to show the impact of increased energy prices on energy-consuming goods. Technological improvements and substitution of other commodities for EIMs significantly reduce the impact of higher prices.

Rapid declines in energy intensity can be achieved (for example, in the cement industry before the 1970s). Energy-intensive sectors may experience some dramatic productivity declines, but gradual savings in energy over 40 years (from 1970 to 2010) should result in reductions of 21–40% in the energy coefficients.

## **Conclusions for Developing Countries**

The demand for EIMs continues to be strong in countries that are developing their infrastructure. Surpluses in production capacity are still concentrated in industrialized countries. However, production capacity continues to increase in developing countries as income increases. It is likely that export capacity will shift to countries with lower energy costs and vigorous markets. In some cases (for example, Brazil, Indonesia, the Middle East, and Venezuela), the willingness to price energy (gas) below its economic cost will attract development of the aluminum industry.

The steel industry has developed mini-mills that are attractive to developing countries because of their lower investment cost per tonne of capacity, faster construction times, and lower energy costs. However, the optimum size of a steel plant is still considered much larger than mini-mill size, and the attraction of locating large steel mills in oil-producing developing countries (for example, Algeria, Iran, Mexico, Nigeria, Saudi Arabia, and Venezuela) was outlined by the United Nations Industrial Development Organization (UNIDO) in 1980. For the chemical industry, supply of feedstock may offset market proximity and may favour developing countries. For all three industries, the location of future capacity will be affected by the large markets of developing countries and by the fuel-cost advantages of oil- and gas-producing countries.

## **Suggestions for Further Research**

EIM requirements must be considered to forecast demand. The trade-offs between importing energy to produce EIMs and importing EIMs that are produced elsewhere should be explored. Research on the future international division of labour in EIM production should include

- Assessing the EIM–GDP break-even point for specific countries and commodities,
- Examining the assumptions and other considerations that have led to increased production of EIMs in developing countries,

- Exploring the agglomeration principle that attracts EIM production in steel, wood pulp, and paper, and
- Exploring both the backward links to nonenergy inputs and the forward links to second-stage processing in developing countries.

# **Transportation and Energy: A Survey and Discussion of Research Needs**

*David Geltner*

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## **Overview**

This paper outlines the contribution of the transportation sector to development and defines the energy problems related to the sector. It also discusses the economic policy literature, the technological and engineering literature, and the institutional, finance, and planning literature related to transportation energy and the achievement of energy efficiency.

## **Analysis**

A transportation system contributes to production, distribution, communication, and integration in an economy. Generally, it accounts for 20–40% of all petroleum use. The transportation sector includes informal, noncommercial, and nonorganized transportation, private motorized passenger transportation, commercial motorized transportation, and private freight transportation provided within firms. A fifth part of the transportation sector is the building, maintenance, and repair of infrastructure, facilities, and equipment.

Although the value added to production by the transportation sector is estimated at only about 5% for most countries, its contribution is essential for economic development. In developing countries,

most transportation is by road (because rail networks are limited and are focused on exports) and includes nonmotorized transportation. A key role is also played by air transportation because of its relatively low capital requirement. In general, the industry that supports the transportation sector is small, and the demand is met by imports (Brazil, China, India, and Mexico are notable exceptions).

The energy intensity of the transportation sector varies among countries because of the market share and energy intensity of each mode and the size of the country. The fundamental energy problem in this sector is the high cost of petroleum, which has increased the percentage of world income absorbed by petroleum costs. Four possible solutions are proposed to improve energy efficiency in the transportation sector:

- Reduce the amount of transportation required by making changes in location and infrastructure.
- Increase the use of less energy-intensive modes of transportation.
- Make technological changes to reduce the energy intensity of each mode of transportation.
- Reduce the demand for oil by modifying engines and developing substitute fuels.

## **Economic and Technology Issues**

A review of the rules for pricing and investment focuses on cost-benefit analysis. Theoretically, pricing should achieve marginal social opportunity cost, and investment should maximize total net social benefits. However, the costs of transportation to the individual user include the value of time and convenience, and this value must be incorporated in the investment equation. Price distortions imposed by other government policies must also be incorporated. A review of different pricing rules suggests that “second-best pricing” policies prevail.

Economic modeling of supply and demand reveals interesting trends. On the supply side, economies of scale are not found to necessarily improve energy efficiency. Transportation outputs

should be defined carefully to show differences in the quality of service. On the demand side, there is an inelastic demand for transportation that is related to the cost of lower-priced modes of transportation. This results in a relatively inelastic response of the transportation sector to increases in fuel prices.

Studies on technology and engineering systems point to improved efficiency with larger vehicles and modes of transportation and to the efficiency potential of advances in combustion control, new engine types, improved transmissions, and new fuels (particularly biomass).

Research into institutional and planning structures suggests that the preferred policy approach includes more efficient energy pricing, less government regulation, and reduced subsidies for transportation services. The use of high energy prices to justify capital-intensive improvements in transportation should be avoided.

## **Suggestions for Further Research**

A synthesis of the information already gathered from economic, financial, engineering, and political studies is most important. It could be used to conduct case studies in specific countries or studies of specific policies.

Additional basic research would be useful to

- Develop energy-saving investment rules for transportation and practical guidelines to estimate energy savings and shadow prices,
- Develop econometric data on the demand for energy for transportation, especially demand elasticities and cross-elasticities of demand in developing countries,
- Develop biomass-based fuels (which do not require prime agricultural land) to substitute for both gasoline and diesel fuels,
- Explore the feasibility of electric vehicles in developing countries, especially light-rail mass-transit and battery-powered vehicles,

- Explore urban planning and land-use control to promote non-motorized methods of personal transit, and
- Explore the role of deregulation and privatization of transportation services to improve energy efficiency.

# **Urban Energy Use in Developing Countries: A Review**

*Jayant Sathaye and Steven Meyers*

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## **Overview**

This paper reviews the use of energy in the urban home for cooking, lighting, and other energy-intensive activities. Urban transportation (mass transit and cars) and commercial and institutional needs are also important in an urban setting. Factors that influence energy use, including the impact of government policy on efficiency, are considered.

## **Analysis**

Increased urbanization is a hallmark of development. In 1984, urban dwellers made up 78% of the population in industrialized countries, 34% of the population in lower- to middle-income countries, and 20% of the population in lower-income countries. Urbanization also brings changes in the collection, distribution, and consumption of energy and leads to increased energy use because of growth in income and the associated increases in demand for services.

## **Household Use**

Cities often promote change in cooking fuels from traditional fuel-wood and charcoal to modern fuels (for example, kerosene, liquefied



petroleum gas (LPG), and electricity) because of higher incomes and the increased availability of the modern fuels. Among the lower-income groups in cities, wood continues to be used for cooking, even when a lengthy trip is necessary to collect the wood. Lack of wood accelerates the transition to modern fuels if these are available. Often homes have more than one cooking device, which offers the flexibility to respond to interruptions in fuel supply. With the use of more efficient fuels and devices, the actual monthly energy use per capita may decrease, but energy demand may remain constant.

In major urban areas, some fringe areas may use kerosene for lighting. However, in areas where electricity is provided, higher income brings more demand for the service. The first appliance acquired by an urban family is a refrigerator, and ownership rates grow with income. Water heating has a much lower priority in urban areas, and air-conditioning is uncommon, except in the wealthiest families. Families are quick to acquire other appliances (for example, televisions, rice cookers, and washing machines) as income grows. Increased efficiency in cooking devices is soon outweighed by the additional energy demands of these appliances.

## **Transportation Use**

In cities, the options for transportation vary from bicycles and rickshaws to motorcycles, buses, and cars. Mass transportation around cities usually involves privately or publicly owned buses that provide different levels of service and energy efficiency. Within cities, new modes of transportation exist (for example, shared taxis and mini-buses). Cars are owned by the wealthiest, and ownership rates vary with the cultural norms in different countries. Buses are 5–10 times more energy efficient than cars on the basis of passenger-mile costs.

Because the number of car trips taken correlates to income, the share of the total expenditure on energy that is accounted for by gasoline and diesel fuels also increases with income. In Kuala Lumpur, for example, the share was found to be 6% for low-income groups and 46% for middle- and high-income groups. The proportion of total income spent on fuels was 1% for low-income groups, 6% for middle-income groups, and 3% for high-income groups.

## **Commercial and Institutional Use**

Few studies have been undertaken on the use of energy in the commercial and institutional sectors. The percentage of energy used by these sectors in urban areas is related to the number of food services and to the number of recreational, religious, and educational establishments. Most energy is required for lighting, ventilation, cooking, and air-conditioning, and energy represents a significant operational cost in these sectors.

Government policies have had an impact on the demand for energy in urban areas. In the transportation sector, the price of fuel has affected the transportation mode, the modal efficiency, and the demand for transportation services. Import tariffs based on fuel efficiency have resulted in more efficient fleets, and programs have been used to promote new fuels from indigenous sources. In the household sector, pricing programs have been used to encourage the import of energy-efficient appliances. In the commercial sector, energy audits, management training, and standards for energy use in buildings have been used to encourage conservation.

## **Suggestions for Further Research**

Patterns of urban energy use must be studied in association with the activities that require the energy. The changes that are caused by increases in income levels must also be understood (for example, switches in the type of fuel used for cooking and the purchase of cars). Cross-country research may provide rules of thumb that could be applied elsewhere.

# **Energy and Agriculture: A Review**

*Ramesh Bhatia and Rishi Sharma*

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## **Overview**

The agricultural sector is both a consumer and a producer of energy. This paper presents data on the use of both direct and indirect energy, by crop, by fuel type, and by agricultural process (for example, irrigation, land preparation, and harvesting). Data on the production of energy from crop residues and dung are reported, and conclusions are drawn about the optimum use of agroenergy production.

## **Analysis**

The use of agricultural products for fuels raises the question of whether to use crop residues and dung for cooking, and thus lessen deforestation, or to ferment the residues to produce alcohol or gas for cooking. Either way, fertilizers are required to replace soil nitrogen. This dilemma poses energy questions related to the agricultural system. A systems approach to energy use in agriculture has rarely been undertaken, and when it has, studies vary in coverage and approach, which makes comparisons useless.

For energy purposes, farm systems can be characterized according to type (seasonal, plantation, and livestock), size and organization (private or collective), level of commercialization, and extent of irrigation. The key elements that determine energy use are irrigation, crop type, the technology applied (bullocks or tractors), and farm size. The last element infers a certain efficiency of technology use

and an appropriate choice of energy source (for example, bullocks or tractors).

Energy use varies by crop and across countries and depends on the type of technology or fuel used. The sum of energy inputs (from humans, animals, fuel, oil, seed, fertilizers, insecticides, herbicides, and irrigation) is more or less equal for both mechanical and traditional farm systems. As farm systems mechanize or change from purely traditional energy types (animal and human energy), irrigation is first improved, then threshing. Harvesting and drying are usually the last activities converted from human or animal labour.

From 1972 to 1980 there was a 117% increase in the consumption of commercial energy in the agricultural systems of developing countries. This increase was accounted for mostly by fertilizer use. However, the same increase was not recorded in crop output. In India, for example, fertilizer consumption rose 257%, but crop yields rose only 23%.

## **The Economics of Energy Technologies**

The sources of energy for irrigation include human, animal, electric, diesel, wind, solar, and biomass. Improvements have been made in the efficiency of hand-pumping devices and of shallow tubewell irrigation. Some countries (for example, India) have many modern irrigation systems powered by electric and diesel pumps. Subsidies are offered on both the equipment and the power to operate the electric pumps. In India, calculations on the farm size needed to financially support this type of irrigation range from 0.8 to 10.2 ha. The true social costs of irrigation, however, are likely higher because of subsidies. Questions remain about the choice of diesel in preference to electric pumps.

The economic and social costs of displacing animals and humans with tractors differ. Although the financial cost of a tractor ranges from three to six pairs of bullocks, the social costs inherent in displaced labour, the effects on foreign exchange, and the concomitant increase in farm size are more dramatic. Harvest operations can account for one-third of the total energy costs of a crop like rice. Because the harvest must occur over a short period, it offers

high wages and attracts urban dwellers. In India, the costs of reaping were approximately equal whether done by tractors or by humans. Threshing is often converted to mechanical power to ensure rapid completion, but combines are economical only on large farms and likely have a high social cost.

## **Agriculture as a Producer of Energy**

Crop residues often significantly exceed grain weight (for example, for maize the ratio is 2.08 : 1 and for cotton the ratio is 7.55 : 1). The residues can also provide a high percentage of animal feed or cooking fuel. Dung is usually estimated to weigh 30% of the fodder consumed, and it can contribute substantially to both cooking fuel and plant nutrients. In Bangladesh, 90% of the energy used in agriculture is produced in the system (principally as animal fodder and plant nutrients).

Countries like China, Egypt, and India, which use a high percentage of traditional fuels in agriculture, function almost as a closed system by using energy from agriculture to produce food and energy. The efficiency of agroenergy use can be improved if biogas and ethanol are produced from crop and animal residues. India has had experience with ethanol production from sugarcane; the profitability depends on the relative prices of sugarcane and oil.

Animal dung is more efficient in energy terms as a fuel than as a fertilizer. However, biogas digesters produce a clean fuel for lighting and cooking, and the plant nutrients in the slurry can be used to fertilize crops. To make this technology more widespread, the cost of biogas equipment must be reduced, appropriate alternative feedstock must be found, and the efficiency of gas utilization must be improved.

To be feasible, biogas outputs must substitute for other previously purchased commodities (for example, fertilizer), the primary barriers are social and organizational, large community-size plants and commercial-feedlot plants look promising, and fuel subsidies continue to distort the viability of biogas plants.

## **Suggestions for Further Research**

To improve research on agricultural energy, researchers must adopt consistent methodologies and measurement techniques and use a large sample size to produce relevant, credible, and comparable results.

Research is needed to produce

- A consistent set of comparable data on the use and the costs of energy sources for various farming systems, crops, and climates,
- Estimates of crop and animal residues in various countries,
- An assessment of the energetics of work animals, and the development of methods to improve their work capacity,
- An assessment of the energy implications of improvements in the efficiency of the use of water and chemical fertilizers,
- An assessment of the use of compact crop residues in boilers, and
- A summary of the socioeconomic impacts of ethanol programs in Brazil, India, and other countries.



## Volume 2

# Energy Demand: Analysis, Management, and Conservation

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*Volume editor: Mohan Munasinghe*



# **Energy Demand Analysis in Developing Countries**

*Ramesh Bhatia*

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## **Overview**

Energy demand analysis (EDA) is an important component of integrated energy plans and policy in developing countries. Planners and policymakers must understand the factors that affect the growth and pattern of energy demand to forecast energy demand and design policies for energy conservation. In turn, the analysis of demand requires the assembly of a consistent set of data (broken down by energy type and end-use sector) on the consumption of, and demand for, various forms of commercial and noncommercial (traditional) energy.

This paper reviews methods used to estimate consumption and demand. It includes estimates for commercial and traditional energy forms, methods of aggregation, data presentation, assessment of unfulfilled demand, and analysis of the shift from noncommercial to commercial sectors. Methods to analyze changes in energy consumption and demand are addressed (including methods of EDA at the macro and sectoral levels). Finally, a number of research issues pertaining to improved EDA are identified.

## **Analysis**

### **Methods for Estimating Consumption and Demand**

**Estimates for Commercial Sources** — Although data on commercial forms of energy (for example, coal, natural gas, and electricity) are generally available, substantial effort may be required to assess the quality of information and to develop a consistent database for energy production, trade, and final consumption. Some of the difficulties encountered in developing a consistent set of energy tables include

- An inability to distinguish between transformation uses or losses and final consumption,
- Problems in separating consumption figures into relevant end-use sectors (for example, retail diesel sales do not identify the quantities consumed by trucks, buses, tractors, and irrigation pumps),
- Difficulties in distinguishing between energy consumed as fuel and energy consumed as a feedstock, and
- A lack of data on indirect fuel exports (for example, sales of oil products to international airlines and energy exchanges between neighbouring countries).

**Estimates for Traditional Sources** — The data on noncommercial forms of energy are generally weak. Surveys are necessary to collect information on the consumption of biomass and of animal-derived fuels. Data are also required on the energy content of these fuels, variations in moisture content over seasons, and energy conversion and appliance efficiencies (for example, the efficiency of wood-to-charcoal conversion and of cooking with woodstoves). The estimates of energy use must also be cross-checked with the estimates of animal stocks and biomass resources. The consumption data should be presented in terms of end uses such as household cooking and heating, industrial heating and steam-raising, brick-making, and animal work in agricultural operations.

**Methods of Aggregation and Presentation** — The use of standard energy conversion factors (for example, tonnes of oil equivalent) to aggregate fuel-specific energy use may distort the relative contribution of each energy source. These accounting measures do not recognize differences in fuel quality (for example, oil is a more convenient fuel and has higher efficiency than coal in many end uses). Therefore, data in original (natural) units should be used, and aggregation should indicate only rough orders of magnitude. Animal energy can be measured by estimating the number of work animals and converting this to energy output based on output (for example, 1.3 MJ/h) per animal, using the energy equivalent of the fodder consumed by the animals, or estimating the diesel oil that would be required to replace the animals with tractors.

Two methods of presenting data on energy transactions are the energy balance table (EBT) and the reference energy system (RES). The EBT presents data on energy production, imports, transformation losses, exports, and final consumption in a consistent matrix format. The RES focuses on estimates of the efficiencies with which fuels are converted, transported, and consumed by various end-use devices. The RES provides this information in a flow diagram that traces various stages from production to consumption. A time series of EBTs can be used to study the determinants of energy demand, whereas the RES can be incorporated into planning models by using mathematical programming techniques.

**Assessment of Shift from Noncommercial to Commercial Sources** — Estimates of consumption can be used to assess trends in fuel switching between noncommercial and commercial forms of energy. This analysis is helped by the results of special surveys on fuel usage and by studies of the impact of relative energy prices on the demand for these energy forms. A particularly important sector is agriculture, where mechanization increases both the sector's reliance on commercial energy forms and its energy intensity.

**Assessment of Unfulfilled Demand** — Frequently, the consumption of energy does not reflect demand because of supply constraints, transmission and distribution problems, and adverse conditions of income distribution and purchasing power. Two approaches to estimating unfulfilled demand are special surveys of energy consumers and the collection of indirect evidence (for example, greater deforestation, illegal sales, and increases in the prices of uncontrolled fuels).

## **Understanding Changes in Consumption and Demand**

**EDA at the Macro Level** — Some of the many ways in which energy demand may be analyzed include

- Comparing the growth rate of energy use with the growth of GDP over a given time and estimating the elasticity of energy consumption with respect to GDP,
- Computing energy consumption per unit of real GDP over time and interpreting the results with respect to trends in the energy–GDP ratio,
- Estimating the demand elasticity with respect to GDP based on regression analysis over historical data (observations) on GDP and energy consumption, and
- Using general equilibrium models that take into account the interactions among economic output, sectoral patterns of growth, energy prices, and energy consumption.

The analyses should be done separately for commercial and total energy and for different sources of commercial energy. This will ensure that the generally weak database for consumption of traditional energy forms does not affect the analysis of commercial sources of energy.

**EDA at the Sectoral Level** — Macro analysis does not identify sector-specific factors affecting energy use. To identify these factors, sectoral models of energy demand must be developed and adapted to the availability of data and the causal factors involved in each sector

(for example, agriculture, industry, transportation, and households). To ensure consistency across the sectoral studies, it is advisable to use the database embodied in EBTs as the starting point for the analysis. The sectoral studies should then attempt to quantify the relationship between sectoral energy use and economic variables (for example, sectoral output, energy prices, and demographics).

## **Suggestions for Further Research**

Research is needed to

- Identify end uses in which traditional fuels are most important, and identify data gaps,
- Study issues such as changes in supply and demand for biomass fuels, including the impacts of conversion and utilization efficiencies and different processes of production,
- Identify the groups facing a shortage in biomass supply, and assess the welfare effects of the commercialization of biomass fuels and the switch to commercial fuels,
- Review and collate the results of studies of energy demand, including the role of energy prices, fuel switching, and energy conservation,
- Assess methods of estimating unfulfilled energy demand and the effects of shortages, and
- Evaluate the social profitability of energy conservation compared with supply augmentation.

# **Policy Issues in Energy Demand Management and Conservation**

*Mohan Munasinghe*

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## **Overview**

The objectives of this paper are to define the role of management and conservation of energy demand in national energy planning, explain their importance for developing countries seeking to achieve rapid overall economic development, propose an analytic framework and a practical implementation methodology, identify appropriate research issues and priorities, and describe several case studies.

## **Analysis**

### **Integrated Planning and the Management of Energy Supply and Demand**

Integrated national energy planning (INEP) is a framework designed to assist investment planning, pricing, and management in the energy sector. INEP is an essential part of national economic planning. Energy supply and demand management (ESDM) is the process used to implement energy plans and policies. Although ESDM has a short-to medium-term orientation, its activities should be consistent with the long-term perspectives and policies defined by INEP. In turn,

energy supply management (ESM) and energy demand management (EDM) are components of ESDM. Energy conservation is a subset of EDM. The objectives and tasks of INEP and ESDM include

- Detailing the energy needs of the economy to achieve growth and development targets,
- Choosing the mix of energy sources that will meet requirements at the lowest cost,
- Minimizing unemployment,
- Conserving energy resources and eliminating wasteful consumption,
- Diversifying supply and reducing dependence on foreign sources to save scarce foreign exchange,
- Meeting national security requirements,
- Supplying basic energy to the poor,
- Contributing specific energy demand and supply measures to develop special regions or sectors of the economy,
- Raising revenues from energy sales to finance energy development,
- Stabilizing prices, and
- Preserving the environment.

To achieve these goals, the policy instruments for ESDM include physical controls, technical methods (including research and development), direct investments or policies to induce investments, education and promotion, and pricing, taxes, subsidies, and other financial incentives. The steps involved in planning include the analysis and forecasting of the supply and demand for energy, energy balancing, ESM and EDM policy development, and impact analysis. The responsible institutions should fall under a central energy authority or ministry of energy. Line agencies (for example, the electric utilities) should implement policies and deliver the product.

## **Shadow Pricing**

Shadow prices represent the costs of goods and services when market imperfections cause these costs to differ from market prices. This is a common situation in developing countries, where market distortions (for example, monopoly practices and market interventions

such as taxes and duties) result in gaps between market prices and true economic values. In the case of traded items, the world price (excluding taxes and duties) can serve as the shadow price. In the case of nontraded items, a more complex set of calculations, based on the marginal social costs and benefits of using a particular resource, may be required. If the nontradeable item is not important enough to warrant individual attention, a standard conversion factor can be used (the ratio of the official exchange rate and the shadow exchange rate). Because the estimation of shadow prices is generally a lengthy and difficult task, it is suggested that previously calculated shadow prices be used.

### **Pricing Policy**

Pricing is an important tool for EDM, especially in the long run. Energy pricing has efficiency and social objectives. The efficiency or economic-growth objective requires that pricing promote an efficient allocation of resources both within the energy sector and between it and the rest of the economy. Efficiency prices are determined on the basis of marginal opportunity cost and include, to the extent possible, environmental costs. Adjustments to efficiency prices are made to account for social objectives (for example, subsidized prices for low-income consumers, a fair rate of return on assets, energy conservation, price stability, simplicity of pricing structures, and promotion of regional or sectoral development). Methods of price control exercised by governments include price subsidies, cross-subsidies (higher prices for some groups subsidize lower prices for others), import and export duties, excise and sales taxes, quotas, and conservation regulations.

### **Energy Conservation**

Energy conservation is an element of demand management that seeks to reduce the use of energy below some level that would otherwise prevail. The reduction involves elimination of waste, decreases in activities that use energy, interfuel substitution, and substitution of



capital and labour for energy. In essence, the adoption of a conservation measure is economically justified if the marginal benefit of energy savings exceeds the sum of marginal costs for additional energy and for nonenergy inputs and the marginal costs of reductions in consumption benefits.

The technical efficiency of energy use is defined by the first and second laws of thermodynamics, which are also known as the conservation and thermodynamic efficiencies. The first law defines efficiency as useful energy output divided by total energy input. The second law efficiency is defined as the theoretical minimum energy required, divided by the maximum useful work available from the actual energy input. The second law efficiency recognizes that a "high-quality" fuel (for example, natural gas) is not ideally matched to "low-quality" end use (for example, space and water heating). Although these thermodynamic concepts are important, especially in energy audits, energy bookkeeping, and energy balances, they should be used only to supplement the economic assessment of conservation measures. They should never be the sole criterion for selecting the optimal level of energy use for a given activity.

## **Applications of Energy Conservation**

The practical application of policies for energy conservation requires a disaggregated analysis of the technical, economic, environmental, and behavioural relationships in each sector-specific end use. Four case studies are used to illustrate an electric power project, a solar energy project, an electricity tariff study, and a conservation measure. A review of more than 30 country studies identifies constraints to effective conservation and suggests a number of corrective measures (Gaskin and Gamba 1983). Other studies analyze the relative effectiveness of various conservation measures (Beijdorff and Stuerzinger 1980) and the policy applications of conservation methods (Pinto 1984).

## **Suggestions for Further Research**

To improve the effectiveness of policy implementation, research should

- Identify the determinants of energy demand,
- Assess the impact and effectiveness of different policy instruments for EDM,
- Seek ways to overcome barriers to the effective application of EDM policies,
- Monitor, adapt, and develop technology to enhance EDM efforts and facilitate the transfer of technology, and
- Study the likely effects of structural and technological changes on patterns of demand.

# **Energy Conservation in the Industrial Sector**

*G. Anandalingam*

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## **Overview**

The development and implementation of technologies that are energy efficient are necessary components of any responsible energy plan. Research and experience in industrialized countries suggest that efficient technologies can play a vital role in improving industrial productivity and sustaining high rates of economic growth. They are also less costly and more environmentally benign than an exclusively supply-oriented strategy. This paper discusses the technical concepts of industrial energy efficiency, reviews energy consumption and the potential for savings in several selected industries, presents the concepts of economic analysis applied to conservation, discusses policy options designed to encourage industrial energy conservation, and suggests a number of research issues that deserve further study.

## **Analysis**

### **Industrial Energy Efficiency**

Energy efficiency is measured using the first and second laws of thermodynamics. The first law defines efficiency as the ratio of energy output to energy input. The second law efficiency is defined

as the minimum energy input required to perform a task, divided by the actual input of energy. Energy conservation measures have the potential to improve first law efficiencies by 10–60% and second law efficiencies by 65–99% in various industrial subsectors.

Industry uses energy not for its own sake, but to satisfy end-use requirements for process heat (40% of total industrial energy use), for a feedstock (20%), and for mechanical drive and other services (40%). In most industries, process heat represents the dominant requirement. Measures designed to improve industrial energy efficiency include investment in efficient boilers and cogeneration systems, recovery systems for waste heat, pipe insulation, and improved housekeeping (for example, boiler maintenance). These measures are cost effective in terms of achieving energy savings with relatively short payback periods. For example, insulation and other housekeeping measures have payback periods under 3–6 months; recovery of waste heat, including cogeneration, has a payback period of up to 3 years; and process modifications and improved mechanical drives have somewhat longer payback periods.

## **Industrial Consumers**

In developing countries, industry typically accounts for the largest share of the consumption of commercial fuel. Generally, the largest five or six industries represent more than 70% of the use of industrial energy. The major energy consumers are the aluminum, cement, chemical (including fertilizers), iron and steel, mining, and pulp and paper industries. Although the food and textile industries are not energy intensive, they too are major energy consumers in developing countries.

Developing countries have higher energy intensities than developed countries. The differences are caused by a variety of reasons (for example, the use of older, inefficient equipment, the use of different technologies, the existence of subsidies on fuel prices, the lack of expertise in energy conservation, and the lack of capital and incentives for investing in conservation). The scope for improvements in energy efficiency is substantial in most industries. The cement industry has the potential to improve by 20%, iron and steel

industries by 10–15%, ammonia production by 5–15%, and pulp and paper production by 10–15%. New processes in the aluminum industry could save about 40% of current energy consumption.

## **Economic Analysis**

Rigorous economic analysis requires more than a calculation of payback periods. Ideally, a discounted cash-flow model should be developed and opportunities to make investments in energy savings should be assessed using such criteria as the net present value and the internal rate of return before and after taxes. A recent study used this type of model to analyze the economics of industrial energy conservation in developing countries. The first part of the study consisted of a comparative economic analysis of measures of energy conservation (based on actual case studies) and of investments to develop new domestic supplies of oil and coal. The second part of the study assessed the impact of government incentives for energy conservation in cases where it was economical from the national perspective but not cost effective for the individual firms. The case studies were selected to provide a representative sample of measures to save energy. The projects ranged from minor changes in energy management in specific firms to industry-wide process changes.

The results confirmed that nearly all the conservation measures were economical from the national perspective as measured by their “supply price” per unit of energy savings. In other words, investments in energy savings provided energy at a cost that was competitive with the cost of investments in conventional new energy supplies. For those energy-saving projects that showed net economic benefits but did not meet commercial investment criteria, the appropriate level of financial incentives (for example, tax credits) was analyzed.

## **Policy Options**

Firms do not make investments in energy savings when barriers make investments in conservation less economical than in a distortion-free economy and prevent the adoption of cost-effective measures.

Economic barriers include

- Fuel prices that do not reflect full social costs (including replacement and environmental costs),
- High costs for conservation equipment because of the low volume of sales, the lack of economies of scale, and the impact of import taxes on foreign goods, and
- High rates of interest and corporate income tax.

Noneconomic barriers include

- Price controls on manufactured products (discouraging firms from improving their energy productivity),
- Inadequate information on energy-saving measures and technologies,
- Lack of technical know-how on energy management,
- Fuel rationing (which encourages firms to maintain their current level of fuel use), and
- A preference on the part of firms for investing in new productive capacity rather than in plant retrofitting and energy savings.

Policies to overcome barriers to energy conservation pertain to pricing, financial incentives, and nonfinancial incentives. Pricing policy should aim to remove price subsidies and make prices equal to economic (including environmental) costs. Tariffs may also be imposed on imported oil, and taxes can be levied on energy products. Financial incentives include income tax credits and accelerated depreciation for conservation investments. These, however, have the potential drawback known as the “free-rider” problem. In this case, incentives are provided inefficiently for all investment proposals, not just for those that require incentives to achieve financial viability. Nonfinancial incentives include standards, targets, and regulations, technical assistance and information programs, and rationing and allocation schemes to encourage energy productivity.

## **Suggestions for Further Research**

Research is needed to

- Estimate the potential for specific energy savings in specific industries and specific countries (starting with an energy audit of major industries),
- Estimate the growing use of commercial fuels in cottage industries,
- Estimate the magnitude of economic disincentives to conservation,
- Create a model to help analyze the effects of various incentive programs,
- Study noneconomic disincentives to conservation in various developing countries to identify implementation problems, and
- Study the links between inefficient energy use and inefficiency in the overall economy.

# **Retail Pricing Policies for Energy in Developing Countries**

*Russell J. deLucia and Michael C. Lesser*

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## **Overview**

Retail prices for energy commodities are generally determined by both market and regulatory forces. Government policy on energy pricing is designed to satisfy several objectives, including economic efficiency, equity of income distribution, demand management, security of energy supply, protection of particular sectors or groups, and increased government revenues. Because of frequent conflicts among these multiple objectives, pricing policies must be analyzed comprehensively. This paper describes various pricing objectives and presents the elements of different methods of analyzing policies on energy pricing.

## **Analysis**

### **The Multiple Objectives**

**Economic Efficiency** — Economic theory suggests that to maximize economic efficiency, and therefore national welfare and income, the price of a good should be equal to its marginal social cost. (This is known as first-best pricing, as opposed to the real world of second-best prices.) Marginal social cost at the wholesale point is based either on the border price for imported fuels or on the marginal



production and delivery cost plus a depletion premium for domestic fuels. The border price of an energy good is defined as its international price plus costs of transportation, insurance, and freight. The depletion premium or economic rent reflects the value of the non-renewable resource in the ground. Marginal social cost can also incorporate an adjustment for the scarcity value of foreign exchange, a security premium (for example, the cost of stockpiling), and the costs of local processing and transportation. If imported crude oil is refined, the lower boundary for marginal cost is the border cost of crude oil plus an allocation of refinery costs to each product according to the relative border price of these products. The retail marginal cost may include additional factors such as the costs of externalities (for example, environmental damage and traffic congestion) and the recovery of transportation system costs.

**Revenue Generation** — Many governments use fuel pricing to generate revenues. Prices are regulated to achieve this objective through import duties and sales taxes, which raise wholesale and retail prices, respectively. Commonly, some fuels are taxed, and others are subsidized. Fuel taxes can also be justified to meet goals of energy conservation. Regardless of rationale, the impact of higher taxes, which distort fuel prices away from efficiency prices, should be analyzed when policies on fuel pricing are set.

**Promotion or Protection** — Subsidies and cross-subsidies on fuel prices lower the retail prices below efficiency levels. These policies are designed to protect particular groups or to promote particular sectors (for example, subsidizing kerosene for low-income users or fuel oil for industrial users). There are several problems with using fuel prices for this purpose. First, subsidies have a direct impact on the national budget. Second, subsidies and price differences can have unintended effects such as providing a subsidy to the wealthy. For example, gasoline is used by both high- and low-income groups and kerosene may be used as much by high-income rural groups (for lighting) as it is by low-income urban groups (for cooking). Third, distorted prices can induce unintended capital invest-

ment or a misuse of fuels (for example, overpriced gasoline leads to overinvestment in more expensive diesel vehicles). Fourth, underpriced fuels “leak” across borders and may be sold locally at inflated prices, particularly if supplies are scarce. More effective policy would offer exporters tax credits rather than subsidies or would give farmers subsidies on inputs that are less likely to leak across borders or to other sectors.

**Price Discrimination** — Price discrimination by consumer and producer groups is relatively easy to administer in the natural gas and electricity sectors because the delivery systems can be controlled and monitored. In general, the price that users are willing to pay differs by type of customer. In the case of natural gas, the fuel is most valuable to users whose alternatives are higher-cost fuels and feedstock. Therefore, in these cases, appropriately designed discriminatory prices can meet both efficiency and revenue objectives.

## Policy Analysis

Policy analysis can be conducted either in a static framework for a particular base year or, preferably, in a dynamic framework for about 10 years. The objective is to quantify the interrelationships and tradeoffs among the multiple objectives of pricing policy. These estimates can pertain to the impacts of various measures on output, employment, household cost of living, prices, government revenues, balance of payments, profits, and welfare or efficiency losses. Sector-specific impacts such as refinery imbalances can also be assessed. The major elements of a pricing study include

- Analysis of pricing policies for energy,
- Economic analyses (international and domestic),
- Analysis of energy use, and
- Impact analysis.

**Analysis of Pricing Policies for Energy** — The first step in a study of fuel prices is to understand current government policies and how taxes and duties are incorporated into wholesale and retail prices. If retail prices differ from efficiency prices, the analysis

should determine whether the differences are an effective way to attain the government's objectives. In a pricing study in the Philippines, some of the scenarios developed to address the goals of the policymakers were

- Efficiency (world prices of fuels, shadow price of foreign exchange, security premium, and transportation system cost recovery),
- Modified efficiency with resource constraint (definition of constraint (for example, constant share of GDP) and constant tax per litre of product),
- Demand management (adjusted prices to eliminate refinery imbalances and to promote energy conservation), and
- Tradeoffs between efficiency, revenue, and household impacts (economic losses associated with distortions in fuel prices and tradeoffs between household impacts, revenue, and demand management).

**Economic Analyses (International and Domestic)** — Analysis of pricing policies requires projections of macroeconomic variables (for example, world prices of energy, foreign exchange rates, the GDP deflator, and the growth rate and sectoral composition of GDP). Other economic parameters that are needed are the shadow exchange rate and the investment and social discount rates.

**Analysis of Energy Use** — Energy analysis should begin with an examination of energy use by end-use sector and fuel type. To understand the effects of pricing policies on energy use and sectoral output, the relationships among these factors must be characterized. Analytic tools that can quantify these relationships include econometric models (to relate energy demand to prices and output), input-output (IO) models (to capture intersectoral effects and direct and indirect energy use), and engineering process analysis (based on such factors as generic process analysis and plant visits with energy audits).

**Impact Analysis** — Several types of impacts must be considered:

- Sector level (sectoral changes in costs and output can be estimated using IO models),
- Welfare losses, including decreases in producer profits and decreases in consumer surplus (decreases arise when tax-inclusive prices induce producers and consumers to switch to a more expensive mix of other inputs or goods),
- Households (the impact of changes in fuel prices on households can be measured by changes in the cost-of-living index for each household group),
- Revenues and subsidies (revenue impacts are the differences between future government revenues under alternative scenarios of prices for fuel),
- Financial feasibility of supply companies (impact of different pricing policies on cash flow and return on capital),
- Balance of payments (for each pricing scenario, the value of imports and exports), and
- Refinery balance (differences in net revenue from refinery operations).

**Overall Analysis of Pricing** — The selection of a pricing policy should be based on informed discussions that include quantitative estimates of the tradeoffs and relative impacts of a range of pricing scenarios, including the “status quo,” an efficiency scenario, and other relevant scenarios.

# **Wholesale Pricing Policies for Energy in Developing Countries**

*Russell J. deLucia*

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## **Overview**

This paper discusses pricing policies at the wholesale level, with particular emphasis on domestic fuels. First, the factors influencing wholesale pricing, including issues related to the energy-supply system, scarcity rent, risks and contract terms, and other general contract issues are reviewed. Second, various approaches to policy analysis, including sensitivity analysis and contract and taxation schemes, are discussed.

## **Analysis**

### **Factors Affecting Wholesale Pricing**

**Supply Systems** — Some of the characteristics of the supply system that affect wholesale pricing are the source of the fuel (imported or domestic), the characteristics of the fuel (tradeable or nontradeable), the nature of the supply companies (public or private and, if private, local or multinational), and the stage of development of the resource. Each of these features affects how the efficient wholesale price of fuels is determined. For example, in the case of domestic fuels, the efficiency price includes a cost of supply and a scarcity rent. The relative weights of these elements are strongly

influenced by the risks associated with the development of local fuel resources, which are, in turn, related to the characteristics of the fuel system.

**Scarcity Rent** — The framework used to analyze the economic price of a depletable resource is based on the economic theory of exhaustible resources (Hotelling 1931). The theory suggests that the depletion cost today of using a unit of an energy good (for example, coal) for power generation is equal to the present-valued difference, at the time of exhaustion of the coal resource, between the cost of using coal and the cost of using the next-best substitute (for example, oil) for the same purpose. Depletion cost is also called depletion premium, scarcity rent or premium, and user cost. The economic (efficiency) price of coal is the sum of the extraction (producer) cost and the depletion cost. If coal reserves were infinite, the economic price would simply be the extraction cost because the price of the substitute would be irrelevant. At the other extreme, if reserves are small relative to demand and, therefore, the time interval to resource exhaustion is nearly zero, the economic price is close to that of the substitute.

It is often assumed that the scarcity rent is captured by government, whereas the cost of supply goes to the supply company. In practice, the distinction is less clear. Supply costs depend on more than physical factors and include the economic returns required on not just capital, labour, and other material inputs, but also risk, the use of scarce knowledge or technology, and the structure of the market (for example, control of information or technology). These complications are often present in the supply of coal, oil, and natural gas, and they influence how much of the scarcity rent is captured by the government. The negotiated sharing arrangements for these rents is a critical element of pricing policy for developing countries.

**Risk and Contract Terms** — The earlier the stage of development of the resource, the more difficult it is to distinguish the cost of supply from the scarcity rent and to determine who captures the rent. Contracts between suppliers and governments must address a

number of uncertainties pertaining to geology (the size of the resource), markets (future world prices of energy goods), and contracts (how the partners will live up to their agreement). Governments generally want to minimize the cost of supply and maximize both the scarcity rent and the portion that is captured by them. In contrast, suppliers want to maximize the supply cost and, therefore, the portion of the scarcity rent they capture. Policies that both minimize the cost of supply and capture the maximum scarcity rent are not easily designed, particularly because of the risks that affect the supply cost. Many tradeoffs must be made. For example, a stringent policy can deter investment, whereas a lax policy raises the effective cost of supply and allows much of the scarcity rent to flow to suppliers. Efficiency goals may also conflict with revenue considerations. Governments generally have large current-revenue needs, and these lead to policies with contracts and tax regimes that distort the investment decision away from the most efficient one. However, more flexible contracts and tax policies have been devised recently.

**General Contract Issues** — In contracts, a critical factor is the sharing of risk. If the government chooses to bear the risk, it may offer a “pure-form service contract” in which the supplier receives a specified return on investment regardless of the success or failure of the project. More common are “risk-service contracts” in which the supplier bears the geological risk and gets a service contract for resource development if an exploitable reserve is found. The degree to which costs and returns are fixed or conditional is important. For example, fixing the expenditures for exploration or development is relatively easy to administer, but it may lead to overinvestment or underinvestment. A different and more usual alternative is to fix the amount or rate of the revenue stream by using either a percentage share or an income or profit tax independent of the relative success of the project.

## **Policy Analysis**

An overall study of pricing policy specific to wholesale pricing contains an analysis of the scarcity rent and an analysis of domestic

pricing, taxation, and contract structures. Other elements relevant to both retail and domestic wholesale pricing are the generation of government revenue and an estimate of how the pricing policies will affect the finances of supplier companies.

**Sensitivity Analysis** — An example of an estimate of efficiency prices that includes sensitivity analysis is the study done for the Electricity Generating Authority of Thailand (Meta Systems Inc. 1983; PEIDA 1983). The purpose of the study was to establish the economic transfer price of lignite for power generation, which in turn could be used to determine the appropriate level and structure of electricity rates. Some of the key study tasks included evaluations of lignite reserves, estimates of mining costs, projections of alternative uses, calculations of the costs and value of lignite, analysis of substitute fuels, and adjustment of economic prices to reflect non-efficiency objectives. The risks that were considered included future demands for lignite, international prices of energy commodities, and the size of lignite reserves. An important source of uncertainty was the future price of imported coal. The analysis showed the impacts of different energy prices on the economic price of lignite.

**Contracts and Taxation** — An example of a comparative analysis of different contract and taxation schemes is the study by Palmer (1980). A simulation model was used to compare a proportional profits tax, a version of a resource-rent tax, and a “tripartite” tax. The resource-rent tax is a high tax on profits after a prescribed return has been achieved. The tripartite alternative was designed to combine the resource-rent tax and a corporate tax that included conditional accelerated depreciation. Ideally, the tax scheme that is selected will collect a high fraction of the rent but not squeeze the supplier to a point below the target return, which represents the investor’s supply price. The pure resource-rent tax always collects the same percentage of rent. The proportional profit tax is the least attractive because it sacrifices collection of some rents (relative to the resource-rent tax) from highly profitable projects and pushes returns below target for marginally profitable endeavours. The tripartite tax appears to be the



most attractive alternative because it comes close to capturing the rent share of the pure resource-rent tax at high levels of profitability and narrows the range of profitabilities in which investors' returns fall below target.

The analysis of issues surrounding scarcity rents, contracts, and taxation policies must be tailored to specific countries and situations. It should consider, for example, the treatment of local taxes under the tax code of the supplier's home country (or dividend distribution for local subsidiaries of multinationals) and the administrative feasibility of the various policy options.

**Volume 3**

**Energy Economics**

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*Volume editor: José Fernando Isaza*

# **Economics of Energy and Natural Resources: Review of an Expanding Field of Transdisciplinary Research**

*Alvaro F. Umana-Quesada*

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## **Overview**

This paper reviews the literature on energy economics. Assumptions are made about the efficacy of prices to signify levels of resource scarcity and thus stimulate efficiency of use, the expectation of progress in technology to find substitutes for exhausted supplies, and the physical limits to the availability of resources, particularly in the area of minerals. Optimists and pessimists clash over questions about price indicators and technology and the methods employed to evaluate the nonmarket benefits of environmental services. In other words, can shadow prices effectively capture the social and ethical values implied in a holistic, analytic system?

## **Analysis**

The eagerness of some authors to discover a new paradigm to topple the neoclassical system has pitfalls that might lead to oversimplifications and border on pseudoscience. Other authors take a more balanced view and recognize that insight can be gained by introducing the concept of entropy in the economic process — in particular by redefining the nature of production, consumption, and capital accumulation.

The central debate is whether current projections of increasing energy-material consumption bear the seeds of their own destruction or whether increasing prices for scarce resources and enlightened technology will restrain the overuse of natural resources and lead ultimately to an unlimited cornucopia. Although historical trend analysis demonstrates a potential for both outcomes, these questions are not amenable to unbiased scientific inquiry. The debate is further complicated by the lack of communication among physical and biological scientists on one side, and economists and most social scientists on the other.

Three distinctly different approaches to energy analysis are net energy analysis, which defines the problem in terms of energy efficiencies in material transformations; energy balance analysis, which is essentially energy accounting; and energy theories of value, which view the embodied energies of economic goods and services as a true measure of the social costs of production and consumption.

Many of these issues are unresolved and suffer from the weakness of single-factor theories. Economic analysis is clearly far more complex, and economic efficiency is not necessarily equal to physical or engineering efficiency. Much of the literature extends thermodynamics to broader issues of ethics, intergenerational equity, and the organization and dissipation of social systems. The early proponents of this approach attempted to apply the principles of the laws of thermodynamics to social policies because they recognized the need to incorporate the energy budget of the planet in long-term social planning. More recently, these ideas have reemerged in the growing literature of systems analysis and emphasized, in particular, the properties of the behaviour of complex systems and their influences on social evolutionary processes.

Economists are concerned about the proper rate of exploitation of exhaustible resources. The resource economist Gray rightly recognized that this question needed to be restated in terms of a socially optimal arbitration between present and future consumption. Gray (1913) developed the "present value maximization criterion" and explored the influence of interest rates on the level of extraction of natural resources. In other words, the problem was posed in terms of

maximizing income streams from fixed assets. These questions were further formalized in the "Hotelling Rule," which states that the net price of an exhaustible resource must grow at a rate equal to the rate of interest (Hotelling 1931). The concept of the discount rate (the inverse of compound interest) was introduced to take into account the preference of current to future consumption, including the risk that future incomes might never be realized. Under ideal assumptions about resource markets, the optimum rate of exploitation would maximize the (discounted) income stream that could be derived during the life of the asset.

Another economic issue in this analysis is the implication of resource substitution caused by growing scarcity or the discovery of cheaper (and abundant) alternatives. Further complexity is added to the analysis if future social trends and changes in values (implied by the ethics of conservation) are anticipated. Much of this analysis is concerned with policies on the management of common property. The dilemma is clearly laid out by Hardin (1968).

A natural resource is an economic concept. Resource boundaries (inclusion and exclusion) vary with cultural values and technological possibilities. These inherent ambiguities in the definition of natural resources lead to considerable confusion in economic analysis. Classical economics viewed land, and the destructible properties of the soil, as a limiting factor of production. Neoclassical economists largely ignored this factor and emphasized the role of (reproducible) labour and capital in economic growth. Recently, "land" has been rehabilitated, redefined as environmental carrying capacity, and once again viewed as a limiting factor.

Reserves of minerals and fossil fuels are also defined by economic, as opposed to geologic, variables. What constitute a reserve are access and the cost of extraction, and these, in turn, are functions of the state of technology and selling price. New discoveries of minerals are correlated to growth in output. This counter-intuitive observation is a function of investments in exploration and development that provide a cushion between annual (projected) output and proven reserve stocks. Four caveats should be noted to dampen the overly optimistic viewpoint of infinite future supplies. First,

although the global supply of minerals may not be threatened by shortages, local (or regional) exhaustion of reserves could have a catastrophic effect on local and national economies. Second, the recoverability of minerals depends to a large extent on spatial distribution, concentration in orebodies, and depth of orebodies. Therefore, some rare minerals may, for practical purposes, become exhausted. Third, there are steep energy costs (in some cases a 10-fold increase) associated with extracting very low grade minerals or difficult-to-access reserves (for example, deep offshore oil). Fourth, although in principle minerals are recyclable, recycling is very expensive.

The distinction between nonrenewable and renewable is largely based on convention. For example, the conversion of a tropical rainforest (a renewable resource) to agricultural use is for all practical purposes a permanent loss. Similarly, extinct genetic stock is nonrenewable. Nonetheless, it is useful for analytic purposes and policy options to distinguish between biological resources that are renewable systems and nonrenewable minerals such as fossil fuels. Nonrenewable minerals and fossil fuels present problems in the choice of the rate of consumption (intergenerational equity), whereas with biological resources the question is largely of social values in environmental conservation and protection.

Economists are drawn to optimization models. Faustman (1968 [1849]) pioneered the development of models of forest management based on the timing of harvests (rotation rates) to maximize income streams over an indefinite time (in perpetuity) given prices, interest rates, and costs of stand maintenance and harvest. Similar models have been developed for fisheries. These fisheries models need, in addition, to consider problems of common access to stocks and uncertain estimates of fish populations.

According to Georgescu-Roegan (1979), the problem with natural resources is their intergenerational allocation. The pioneering work in the development of models of optimum exploitation (maximization of the stream of potential income) depended on assumptions based on complete certainty about the availability of resource stocks and future demands, perfect information and competitive

markets, constant marginal extraction costs, and no externalities. Given that resources in the ground are unproductive, the only way owners can earn a return on them is through capital gains that result from price increases. These increases must parallel the market rate of interest. Hotelling (1931) demonstrated that the application of this principle is a necessary condition for maximizing the present value of producer and consumer surpluses in a partial equilibrium framework. Much of the subsequent theoretical work has been aimed at applying the Hotelling Rule to conditions of uncertainty in knowledge and in future prices of resources. In other words, attempts to explain, under real world conditions, observed price behaviour and planning decisions in the mining industry.

The economic model for optimizing present value is based on the premise that an appropriate discount rate can be found to arbitrate the allocations between present and future consumption. This approach has raised several objections not only because of the uncertainty in future supply and demand, but because of ethical considerations about discounting the potential well-being of future generations. As Ramsey (1928) put it, "Although a person may have grounds for discounting future benefits because of uncertainty, impatience, or weakness of imagination, this is not necessarily appropriate for society as a whole." The legitimacy of using the discount rate to determine the rate of depletion of exhaustible resources depends on unknown answers to such questions as the efficacy of substitution, the compensation in growth of manufactured capital stock, and, in general, whether in balance (for example, through technological advances) the future generation will be better or worse off than the present generation. A zero, or even negative, discount rate may be the most appropriate choice if resource depletion leads to long-term impoverishment.

A major controversy among resource economists is the capacity to resolve the problem of resource scarcity. Some take the view that technology will free the world from the traditional material and energy bonds by substituting relatively abundant resources for potentially scarce resources. Others see a dilemma in this process. First, the substitute resource may not be inexpensive to produce;

therefore, a low-cost input will be replaced with a high-cost input. Second, an abundant resource, such as fusion energy, must be supported by complex capital infrastructures. The cost of maintaining these systems may ultimately exhaust the producer and consumer surplus. Third, complex technologies are in themselves unstable and therefore increase the potential for chaos and social instability.

## **Suggestions for Further Research**

Although economists generally hold a fairly optimistic view of the potential for long-term economic growth, this view is not shared by earth scientists and biologists, who perceive a steady, and inexorable, degradation of the environment and a depletion of resources. An important conclusion is that the study and resolution of the problems of energy economics and natural resources requires contributions from many disciplines. Although the recent trend toward integration is encouraging, there is still much conflict and misunderstanding about the interpretation of facts and appropriate policy recommendations.

There are serious gaps between the conceptual models of natural resource supply and demand processes and their empirical applications. It is difficult to test a hypothesis derived from theory, and empirical models give notoriously unreliable predictions of how the supply will behave when prices and other economic incentives change. In addition to the problem of predicting supply behaviour, there is a need to integrate these models into macroeconomic frameworks and, moreover, place greater emphasis on externalities of production. Therefore, models of resource exploitation and processing should account for waste generation and for the effects of pollution and contamination on local and global ecosystems.

New insights into the management of natural resources stem from advances in ecological research and theory. The traditional maximum sustainable yield (MSY) model is considered largely inadequate in light of these findings, which have introduced stochastic fluctuations into population modeling (for example, flow dynamics for nutrients, chemicals, and energy in ecosystems) and emphasized



the need for biodiversity to maintain healthy, productive stocks. Models of complex systems that exhibit chaotic behaviour and dissipative structures are also contributing to the understanding of evolutionary processes in nature. These ideas are generating new scientific paradigms for the strategies of sustainable resource management and promise to open new areas of research in the economics of energy and natural resources.

Finally, there is a need to improve risk analysis and its application to the management of natural resources. This includes the adoption of conservative approaches to identify "safe minimum standards" for critical resources. Further research is suggested on adaptive management models that couple uncertainty in resource management with sensitivity analysis to explore different scenarios.

# **Energy-Related Issues in Early Economic Literature**

*Juan Martinez-Alier,  
with the assistance of Klaus Schlupmann*

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## **Overview**

This paper seeks to explore the origins of the literature on an ecological approach to economics. It is noted that the use of an energy paradigm in economic analysis has been largely undertaken by non-economists and that this continues to be the case.

## **Analysis**

By the middle of the 19th century the quantitative relationship between the amount of solar energy radiating onto the Earth's surface and its conversion to organic matter was known. The process of nutrition as the oxidation of carbon was also understood, as was the use of energy in metabolism and in work. Serhii Podolinsky, beginning in 1880, was one of the first to apply this knowledge to input-output ratios in agriculture. The starting point of the analysis was the laws of thermodynamics. The total quantity of energy in the universe is constant, and the energy used, for heat or work, is transformed from a higher to a lower order of organization (dissipated). This is also known as entropy, or the transformation of energy from available to unavailable forms.

Sacher (1881) attempted to calculate the economic product and process in terms of energy units. The essential thesis was that the natural sciences could provide a rational basis for economic productivity. The importance of the analysis was that it linked economic production with natural energy sources, the ultimate source being solar radiation. In this analysis, the sources of energy were agricultural crops (nutrients) and domesticated animals, wood and other combustible biomass, water and wind, and fossil fuels. Sacher calculated, in kilocalories per day, the potential energy available per person-year in central Europe.

Other important concerns of the time were soil exhaustion and the need to replace soil nutrients. A major problem was the potential exhaustion of the supply of Peruvian guano and Chilean sources of saltpetre (potassium nitrate). What was envisaged was a chemical process of soil restoration based on the application of chemical fertilizers supplied by a reliable manufacturing process. The problem of maintaining a nitrogen cycle in intense agricultural production systems required the support of a large chemical industry. At the time, the side effects of the application of artificial chemicals were not realized — only the benefits of the marriage between industry and agriculture.

Patrick Geddes (1854–1932) was best known for his theories of and ideas on town and country planning; nonetheless, he wrote frequently about the subject of economics both as a critic and as an advocate of an ecological approach. He wrote in the context of the emerging marginalist theories of economics that “they can do everything with no assistance from applied physics for studies of material production, with no assistance from biology for the study of organisms which make up society, with no assistance from modern psychology ... or from research done by the historical or anthropological school!” (Jaffe 1965).

The development of culture, according to Ostwald (1853–1932), depends on the availability of energy and the efficiency of its transformation. This is an “energetics” interpretation of history. Max Weber (1864–1920), in a review of Ostwald (1909), noted the lack of data to support the theoretical assumptions (Weber 1968 [1909]).

Weber also questioned the interpretation of economic processes on such an abstract concept as energy compared, for example, with the concrete reality of materials. Costs appeared to depend as much on material abundance and scarcity as they did on the availability and the efficiency of conversion of energy. Weber pointed to the low energy cost in hand weaving compared with machine weaving, but the machine was less costly in money terms. Although development can be correlated with increases in energy consumption per capita, the question for Weber was whether this apparent availability of energy should be interpreted as a cause of development or whether this merely reflected a tautology.

While Soddy's (1877–1956) scientific endeavours won him acclaim (Noble Prize for Chemistry in 1921) his economic writings were largely ignored. Nonetheless his insights into the nature of production anticipated the modern ecological critique of economic theory. An important distinction is made between the conversion of solar energy to support life and stored solar energy translated into work. In the 19th century, the source of the energy translated into work came increasingly from coal: "sunlight of a hundred million years added itself to that of today and by it was built a civilization such as the world has never seen (Soddy 1922, p. 20)."

Soddy thought that the concept of economic growth based on the accumulation of capital stock was founded on ignorance of physical processes. Entropy, or what Soddy referred to as compound decrement, is an inevitable characteristic of all material structures. The energy cost of maintenance and repair of this stock increases over time and eventually decays. Soddy thought that the projection of constantly growing wealth through compound interest was the ultimate absurdity and that it could not be observed in historical processes. In essence, there is no permanent physical basis for savings to accumulate interest. What is defined as financial wealth merely represents claims on communities' current consumption. This rejection of stock as wealth led to the conclusion that economic wealth should be defined as flow. That is, wealth is revenue, and the source of this wealth is the flow of solar energy.

Joseph Popper (1838–1921) was primarily concerned with the nature of scarcity and with the policies of equitable distribution. His studies were based on calculations of material and energy flows through the economic system and the means to reduce the consumption of exhaustible resources. Popper provided a detailed account of the resources available to the German economy just before 1914, and he estimated the human work requirement to guarantee the whole population a subsistence of food, clothing, housing, education, and health services.

Karl Ballod (1864–1933) could be classed as a technoecologist. His enthusiasm for applying technology to agriculture (mechanization) was constrained by the harmful effects he predicted from large urban agglomerations and the use of private cars. Ballod predicted an oil crisis, pollution, and the decline of the use of public transport. His books on production and consumption in a socialist state were written between 1898 and 1927 and emphasized the need to develop a sustainable economy. Small towns with sufficient gardens to grow food, recycling of wastes, and careful management of resources were all part of his prescription for a pleasant and sustainable society.

All these authors were off the mainstream of economic thought and remained largely unknown. What distinguished their analysis was that, unlike the conventional economic model of a circular flow of exchanges between producer and consumers, they viewed the economy as an entropic throughput of materials and energy. In other words, they saw the need to take into account the unidirectional flow of energy (and also the impossibility of full recycling of materials) in the economic process. The principle that the allocation of resources should respond to the preference of economic agents (backed up by purchasing power) encounters an ontological difficulty. How can current economic bargaining agents represent yet unborn individuals and calculate the risk premiums of unknown futures? Also, as noted by Soddy, the depletion of natural capital is treated as a source of income, whereas consumption of manufactured capital is not. This critique of the economic model is fashionable in today's world of environmental degradation and exponential growth in resource consumption.

# **Energy for Small-Scale Engines: A Review of Potential Energy Sources**

*Christopher Hurst*

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## **Overview**

Mechanization in agriculture can demonstrate growth in output per hectare. This paper examines the technological and economic parameters of small engines (for example, small tractors, pumps for irrigation, and small-scale generators for electricity). The objective is to assess alternative technologies in terms of physical efficiency and capital and operational costs.

## **Analysis**

Biomass fuel has received increased attention as a renewable alternative to petroleum. After several decades of neglect, producer gas (combustible gas generated by gasifier processes) is once again being produced in large quantities, particularly in China and, to somewhat lesser extent, in India. Gasifiers are necessary to produce the fuel to power gasoline and diesel engines. Engines that use producer gas have approximately the same efficiencies as engines powered by petroleum. The traditional biomass gasifier is fuelled either by charcoal (which produces a clean mixture of nitrogen, carbon monoxide, and hydrogen) or by wood or other vegetative matter. Some experi-

mental work is under way to produce small-scale gasifiers at costs sufficiently low to compete with large-scale commercial producer gas. The alternative technology, anaerobic decomposition or biogas, is currently feasible for household or village-level production units. This gas is predominantly methane and can be used directly to power small engines.

The feasibility of harnessing solar and wind energy to drive small engines is also examined. The attraction is that these sources of energy are "free." Nonetheless, the capital cost of converting sufficient quantities of these types of energy for work is relatively high and limits the use of these energy sources. Two methods of energy conversion are direct transfer of heat to power an external combustion engine and conversion to electrical energy by a photovoltaic technique. The technical feasibility of photovoltaics is improving as the production costs of semiconductors are reduced.

Animal work or (metabolized) energy has been the major source of power for pumping water for irrigation. Although several systems have been used for centuries, the most common type is the Persian wheel. However, a major cost is the need for brick- or concrete-lined wells as opposed to much cheaper tubewells. As well, it is feasible (with a very high gear ratio) to use bullocks to drive centrifugal pumps in tubewells. Human power is rarely used to draw water for irrigation. The traditional methods are the Shaduf (a counter-weighted tripod system with buckets) and the hand pump.

For low levels of demand for irrigation water (less than 10 000 m<sup>3</sup>/year), the hand pump and Persian wheel are the most efficient in energy-capital cost terms. Even the photovoltaic cell, if the price was about 5 USD, could be considered as an efficient technology for driving low-capacity pumps. At medium levels of water demand (up to 50 000 m<sup>3</sup>/year), small gasoline-driven (1.5 kW) and bullock-powered tubewells are the optimal technologies. However, after demand reaches 100 000 m<sup>3</sup>/year, larger diesel (3.75 kW) and gasoline (2.25 kW) engines converted to run from charcoal-fuelled gasifiers are most energy and cost efficient. This general order is the same for high-price petroleum, although biogas becomes an increasingly attractive alternative fuel. Renewable energy sources entail

higher costs than fossil fuels when high-level power pumping is required because the capital costs are still high per unit of energy. Nonetheless, animal power and human power are still efficient for low power requirements if realistic Third World opportunity costs are taken into account.





## Volume 4

# Electricity

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*Volume editor: Ramesh Batia*

# **Electric Power: Essential Infrastructure for Development**

*Mohan Munasinghe*

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## **Overview**

This paper explores some of the important ways that utilities in developing countries are seeking to become more efficient in the supply of electricity and the mobilization of resources. Integrated planning and policy, pricing policy, supply efficiency, and the organization and financing of the sector are discussed.

## **Analysis**

The power sector in many developing countries is under pressure to both meet a growing demand, which will hopefully fuel economic expansion, and reduce the inordinately high investment burden the sector represents. In many Latin American countries, for example, costs in the power sector represent more than 75% of energy investments and more than 40% of annual public investment.

One of the primary steps to rationalizing power-sector requirements is the development of an integrated national energy plan. In this plan, investment planning for electricity supply and all other energy forms is coordinated to anticipate the development aspirations and the resource capabilities of the nation. Planning must encompass energy-economy interactions and be detailed at the sub-sectoral level. A second important area is pricing and investment

policy. Utility efficiency is a third key area because resource requirements can be lowered as services are expanded.

## Pricing Policy

Long-run marginal cost (LRMC) tariffs are based on the future costs of economic resources rather than on the sunk or invested costs. This method is a superior format for tariff setting because it is based on the incremental economic cost of providing the next kilowatt of energy, and it gives appropriate signals to consumers about the national cost of the resource. The LRMC approach is flexible because it allows tariffs to vary with a host of variables (for example, consumer categories, voltage levels, and system peaks or time of day). LRMC is the “first-best” approach to setting tariffs.

Practical considerations must always be taken into account; therefore, it is fortunate that LRMC methods provide a benchmark by which to set tariffs while other issues are considered. Some of these issues are of particular importance to developing countries. LRMC-set tariffs are invariably higher than those set to meet the strict financial needs of a utility, particularly when the cost of supply is increasing. This does not necessarily mean that tariffs should be lowered. Rather, it is an opportunity for flexibility when issues not normally brought into LRMC calculations are considered. These include

- Social equity (provision of basic services to low-income customers at subsidized rates),
- Inducements to new customers (subsidies for connection charges), and
- Competition with substitutes (other fuel substitutes such as kerosene may not be priced according to marginal cost principles, and electricity may require subsidy among certain customer classes or regions to prevent excessive use of the alternative).

LRMC principles are counterproductive if the utility is not operating efficiently. Tariffs can be inflated for service that is unreliable. As well, increases in revenue provide no incentive for

utility efficiency. Therefore, a prerequisite for LRMC-based tariffs is supply efficiency.

## **Supply Efficiency**

System reliability and, by extension, system capacity are important factors in the efficient provision of electricity. Traditionally, system planners have attempted to establish programs to supply sufficient capacity at the least cost to meet some implicit criteria for system reliability. This least-cost approach may not be sufficient, and it is better replaced with explicit standards for reliability. This is an improvement because it defines capacity requirements and encompasses other system-optimizing factors (for example, improved operation and maintenance procedures) and design features (for example, conductor size and pole strength). This approach requires that planners develop system costs the same way as they developed costs for variations in system capacity. It also requires a more difficult and qualitative procedure that estimates shortage costs and the “benefits” associated with given levels of reliability. This more dynamic approach is superior, but shortage costs are difficult to estimate.

To operate efficiently, utilities in developing countries must move to greater autonomy and institute management reforms. It is common for a central government to play a strong role in the management and direction of utilities. This interference has led to inefficiencies such as

- Costly procurement and investment decisions,
- Uneconomic setting of tariffs, which leads to high losses, and
- Poor hiring practices and salaries, which lead to declining morale and performance.

Utilities must be reformulated to provide greater autonomy in the operation of the enterprise. Governments should be responsible for broader questions concerning the allocation of resources within the energy sector, but their role with regard to the utility must be buffered by an appropriate board of directors. At the same time, this implies the need for greater accountability (measured against specific objectives and monitored indicators) at all levels of manage-

ment. With appropriate training and experience, managers and employees must be given responsibility for well-defined roles if human resources are to be allocated efficiently.

## **Organization and Financing**

The large public-sector monopolies, which are characteristic of utilities in developing countries, likely lead to inefficiencies. These inefficiencies could be reduced by the introduction of competitive market forces. Resource allocation could be made competitive by

- Contracting civil works (for example, dams, roads, and pipelines),
- Contracting distribution networks, billing, and meter reading,
- Decentralizing into independent regional power grids, and
- Encouraging independent power producers (cogenerators) by ensuring economical, long-term buy-back rates.

Innovative financing options often used in developed countries are also appropriate for developing countries. Some of these include

- Leasing of individual pieces of equipment or whole plants by local or foreign investors,
- Bartering exports for energy imports (counter trade),
- Issuing revenue bonds with yields tied to enterprise profitability, and
- Providing guarantees for international capital investment in developing countries against the financial risk common in these financial environments (these are provided by the Multilateral Investment Guarantee Agency (MIGA) of the World Bank).

# **Markets for Utility Electricity**

*David B. Brooks*

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## **Overview**

This paper explores the markets for electricity in developing countries and focuses on the major grid-fed markets of residential, commercial, and industrial users in urban areas. Concepts of thermodynamic efficiency and supply–demand matching are shown to be important to the development of utility markets. The paper calls for a better understanding of demand in terms of the quantities of electricity and the qualitative factors that influence use. Policy directions that emphasize demand efficiency are recommended.

## **Analysis**

Markets for electricity in developing countries have experienced an extremely high rate of growth — in the early 1980s as much as 9% or more a year. A combination of factors, general to developing countries and specific to rapidly industrializing nations, might explain this growth. The release of suppressed demand, rapid urbanization, industrialization, and the growth of real income are all factors. Several problems constrain the servicing of these markets or put pressure on national capabilities:

- Too many consumers pay less than the “book cost” for electricity.

- Generation projects are subsidized by national or international funding agencies, and the book costs understate actual costs.
- Full costs often overlook unplanned environmental and social costs.

It is important when characterizing markets to identify those aspects that will help focus debate on the physically and economically efficient use of electricity.

Data on use of electricity are good relative to those on other fuels because billing data for the utility are generally segregated by customer class. The main market sectors are urban residential (20–40%) and industrial (at least 40%), wherever that sector is located. The commercial sector is also rapidly expanding, but lack of consistency in defining what customer base is “commercial” and high income elasticity in the customer class have led to confusion in reporting and great variation in data.

Market concentration is clear in urban areas where there is a high demand for this clean and flexible fuel to complement the other infrastructure found in cities. Resource-based industry may create demand nodes in rural areas. Otherwise, rural electricity, although historically a sizable component of a utility’s development budget, does not constitute a large demand. The nature of rural demand may, in fact, place strains on the system by increasing the load factor.

## **Identification of Efficient Markets**

Certain principles can be used to identify appropriate markets for electricity in developing countries. The first principle is that energy services can generally be increased more quickly and more efficiently by improving the efficiency of conversion and generation than by providing more supply.

The second principle is that, of all common forms of energy, electricity is of the highest quality. In other words, to deliver one unit of electric energy requires three units of fuel (for thermal generation). Electricity is therefore a highly refined source of energy that involves high thermodynamic costs in its manufacture. Appropriate markets for this high-quality form of energy are those for which there



are no other efficient or convenient substitutes. There are three reasons for the higher rates of growth in demand experienced in developing countries compared with the developed world:

- Demand for electricity is suppressed by lack of income, lack of electricity-intensive industry, and lack of dependable supply (to the extent that these are reversed, as they are in particular in the newly industrialized countries, rapid growth occurs).
- Governments in developing countries have generally supported development of infrastructure in the power sector that is out of proportion to the actual energy demand that is met by electricity compared with other fuels (this is done for nationalistic and economic development reasons).
- Electricity is used inefficiently, particularly in industry.

## Identification of Markets

**Residential Use** — Growth in the use of household electricity is correlated closely with family income. Even the poorest families will use power for lighting if it is available. As incomes increase, so do uses. Major end uses are lighting, communications and electronic devices, air conditioning, small and large appliances (generally motors), cooking, and water heating. Major efficiency improvements are possible in each of these uses based largely on technological improvements that have occurred in industrialized nations.

Future growth of demand in this sector will result from grid expansion and growth of incomes. This latter factor will be dampened somewhat by the large efficiency improvements that are possible in residential technology.

**Commercial Use** — Major uses in this category are lighting, space conditioning, ventilation, and in some cases hot water. Efficiency improvements are available not only in new technologies (for example, lighting) but in patterns of use and in building design. For example, the use of daylight and appropriate shading of windows can reduce the air conditioning load by reducing the heat produced by lights.

**Industrial Use** — Electricity conservation in industry has the potential for large savings. Examples from developed countries show that reductions of two-thirds of the demand for motor drives, about one-sixth for process functions, and one-sixth for other demands (for example, lighting) can be achieved.

Countering the trend of reduced demand because of efficiency is a higher overall demand from industry. This can be explained by shifts to electricity-intensive processes and the concentration of energy-intensive industries in developing countries. These opposing tendencies create uncertainty about the direction of growth in industrial electricity.

## Matching Supply and Demand

To help focus the discussion of appropriate electricity markets, it is useful to recall that electricity is a form of energy of the highest quality. Three categories of electricity use can be defined:

- Uses for which electricity is entirely or almost always essential (for example, electronics, telecommunications, stationary motors, residential and commercial lighting, and electro-metallurgy),
- Uses for which substitutes are adequate but lack the convenience, control, or cleanliness of electricity (for example, pumping, heating, cooling, and remelting), and
- Uses for which other fuels easily, and perhaps more efficiently, perform the same function (for example, water heating, steam raising, and space heating).

These categories can be useful when priority markets for a utility are determined. However, it is almost impossible to develop hard rules. Much depends on the circumstances within the country (in particular, economic circumstances such as short- and long-run marginal costs of power and political choices).

However, it seems clear that the development of efficiency in markets is constrained largely by institutional barriers arising from lifestyles and habits, those protecting vested interests, and outmoded or misdirected policies.

Of a range of institutional barriers, the ones most specific to developing countries are the lending practices of international agencies. It is apparent that these institutions prefer loans for supply projects rather than loans for conservation projects, although this situation may be changing.

## **Suggestions for Further Research**

Research is needed to

- Better understand patterns of demand for electricity in key sectors (disaggregated by end use),
- Reevaluate load forecasts (based on expectations of savings resulting from improvements in technology) as a basis for showing potential efficiencies,
- Understand patterns of demand for electricity based on the qualitative service it provides,
- Implement efficiency programs based on cost-effective measures and the capabilities of local staff, and
- Consider several factors related to efficiency and conservation (for example, efficient pricing, government policies and programs, education and training, and the development of a focal group, likely the utility, for a conservation program).

# **Recent Research in Electrical Power Pricing and Load Management**

*Richard D. Tabors*

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## **Overview**

The recent experience of utilities in developed countries (Europe, Japan, and the United States) is reviewed with respect to direct-load management and innovative tariff systems and their relevance to developing countries. A gradual, stepped approach to introducing these techniques to developing countries is recommended.

## **Analysis**

An efficient power sector is of tremendous importance to developing countries. Reliable electricity is a key to economic development. The electric-power sector is expanding at a rate that exceeds total energy or GDP. It is the largest consumer of commercial energy (up to 30–40%) and a large consumer of capital (15–20% of development investment).

It is important that electric utilities be aware of, and adapt to, recent developments in technology that are revolutionizing the industry. These changes are forcing a reconsideration of high-cost central generating plants and permitting an unprecedented degree of freedom in communication between utility and customer. Although

systems in Europe, Japan, and the United States will be slow to change because of the massive infrastructure already in place, it is research carried out in these countries that will help direct the development of new systems in developing countries.

## **Pricing of Electricity**

There are currently three approaches to tariff setting that provide increasingly sophisticated means of cost recovery and of sending market signals to the customer. The first and most common approach, often known as embedded rates, is based on the cost of service. Typically, this system seeks to recover capital and ensure return on investment. It encourages increased consumption by incorporating the declining block structure. This system has come under pressure to change because of increases in fuel prices, changes in economies of scale, and greater ability for communication between utility and customer.

A second approach has developed from these changes. It is based on tariff setting from LRMC analysis, and it is strongly promoted by the World Bank.

The third approach argues that the correct base for pricing is the short-run marginal cost (SRMC) and that the best approximation of this cost is the real-time marginal cost to the utility. The most basic of these measures differentiates peak and off-peak periods, 2- or 3-day periods during weekdays, and seasonal periods. These rates are generally available only to large commercial and industrial customers because of metering and billing costs. Increasing complexity can be introduced by increasing tariff steps to hourly or even 5-min blocks. Blocks are restricted only by the ability of customers to react and by the cost to the utility for administration. Equipment and software for the provision of spot pricing to commercial and residential customers are currently under development in Britain and the United States.

Real-time marginal-cost pricing can provide benefits to a utility in a developing country during periods of rapid price transitions (for example, currency devaluations) and during times of high variability

in supply (for example, the variability that might be found in a hydro-dependent system).

## **Systems of Load Management**

The critical issues in a system of load management can be seen in the circumstances that create the need. These are

- Unanticipated system emergencies,
- Times of system peak, and
- The general need for load evening.

Unanticipated system emergencies require fast response times and can be directed either to large, responsive, industrial customers through short-term interruptible rates or to appliances that can be taken off line either manually by the customer or remotely by a signal from the utility. System peaks occur on a more predictable basis. The utility can also control appliances (for example, air conditioners) or use a more flexible system of rates that apply to time of use or spot pricing. Load evening does not require rapid communications and is related to a general smoothing of the load curve.

The response of the customer depends on a number of factors. Generally, industrial customers have the highest response rate to economic signals. The type of communication system the utility uses can influence the response. This communication system can range from a simple contractual statement on time-of-use rates, to appeals for public conservation, to the publication of 24-h spot prices. More sophisticated systems can involve one- and two-way communication over telephone lines, coaxial cable, and radio signals. Interruptible rates are usually used with large-scale industrial users. These rates give the utility the right to demand a specific response from the customer on call. The rate, in return, is concessionary.

## **Suggestions for Further Research**

Research and commercial implementation of load management and of innovative tariff structures have taken place almost exclusively in countries that are members of the Organisation for Economic Co-operation and Development (OECD). A stepped approach to

extending these measures to a representative sample of developing countries is recommended. This would involve

- Case studies of the variable energy costs and of the potential for shifts in load growth in different customer classes,
- An evaluation of the feasibility of load management and innovative tariffs, and
- Pilot implementation and evaluation.

# **Optimizing Electrical Distribution Systems**

*Walter G. Scott*

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## **Overview**

A method is discussed to plan and design systems for the distribution of electricity from the substation to the customer. Computer methods that match the skills and hardware in developing countries are emphasized. Recommendations are made for advanced computer techniques to plan distribution systems that will have supervisory control and data acquisition (SCADA).

## **Analysis**

Proper distribution planning lays the foundation for decisions on construction and operation criteria, quantity and sizing of plant additions, and quality of service. Computerization of plans allows the simulation of options and the optimization of a system plan. The distribution plan is the initial step in the system plan. Distribution plans incorporate disaggregated load forecasts that determine the loading at substations. Aggregate substation loads are a basis for generation plans. Alternative system plans can evolve from this framework if key parameters (for example, voltage levels, conductor sizes, and generation capacity) are varied. Broad feasibility studies can help optimize alternative scenarios and allow the selection of a long-term system plan. These studies should include engineering,



operation, and economic evaluations. More detailed analysis and costing of the selected alternative permit an assessment of the financial impact of the plan on the utility.

Load forecasts are the key to realistic long-term plans for distribution facilities. The primary components of a forecast are future use of land (by consumer class), division of areas into distribution regions, and determination of power and energy requirements (by customer class). Input data consist of load areas, land use, customer density, energy requirements, and historical loads.

## **Systems of Analysis**

Current computer models can optimize the design of the primary system from the substation to the distribution transformers. By varying parameters (for example, conductor size, voltage, loads, power factor, and switching), one can optimize each line section from the substation to prevent voltage drop and line losses.

A transformer model can help design transformer configurations by specifying no-load losses and load losses. Both substation and distribution transformers require configuration. Distribution transformers will be of either US design and serve 2–20 customers or European design and serve up to several hundred customers.

## **System Losses**

In the design of distribution networks, losses have become the primary criterion (rather than voltage) for delivery of services to customers. This shift means that several design features will change. For example, average loading on components will be reduced, the power factor will be controlled more carefully, and operations will be designed for automation.

A study of loss optimization in the Punjab (India) provided the following conclusions:

- Distribution loss is significant and loss reduction should be given high priority because it is a relatively neglected topic.

- Important data for loss calculations are generally available from a variety of sources (for example, peak, peak-equivalent hours, load factor, load duration, and loss factors).
- Load management of distribution transformers uses the metered demand of customers to monitor transformer loading, and investment in this technology shows significant benefits over costs (about 15 : 1).
- Losses are the most important design criterion, but current practice often uses thermal characteristics and reliability as the criteria.
- Within practical limits, it costs less to save power and energy by reducing losses than it costs to increase supply.
- Distribution substations, primary systems, and distribution transformers and secondary lines account for about 10, 55, and 35% of annual losses in the distribution of energy, whereas economic losses in distribution are in the range of 3–5% of annual energy and 5–8% of power at peak.

Advanced computer tools will permit more sophisticated optimization of distribution networks. These tools include graphics (for example, the plotting of circuit diagrams), real-time analysis of voltage, and loading and loss studies that use actual data on substation voltage and loading.

# **Electrical Transmission Technology**

*K.R. Shah*

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## **Overview**

A detailed, technical account is given of recent and past advances in transmission technology for both alternating and direct current. Recommendations are made for a research centre on transmission technology to help developing countries adapt technology to their needs.

## **Analysis**

The capacity of transmission networks has risen steadily. Today, extra-high voltage (EHV) transmission from 34.5 to 230 kV is common in industrialized countries. Technology is available to transmit at ultra-high voltages (UHV) of up to 1500 kV. Attempts have been made to transmit at increasingly higher voltages because costs are reduced as the voltage increases. Transmission voltages are currently constrained by the poor operating performance of large generating stations and by the desire to maintain the system's stability, voltage regulation, and reliability.

High-voltage direct current (HVDC) transmission has gained acceptance for integration into alternating current (AC) transmission grids because HVDC is more economical than AC over long distances, as long as the direct current (DC) connecting link has the capacity and additional transmission capacity can be readily added. The stability of the system is enhanced because of the inherent flexibility in the magnitude and direction of current flow in a DC

system. A comparison of the additional costs of HVDC with the benefits of AC transmission reveals that the break-even distance for overhead lines is 650–1300 km and for underground and underwater cables is 30–100 km.

## **Transmission Design**

The design of lines and their rights of way involves consideration of technical performance criteria and environmental impacts (for example, ecological factors, electrical interference factors, aesthetics, and social benefits). The object of line design is to select line size, clearances, insulation, and number of shield wires. These design features depend on a range of factors (for example, atmospheric conditions, reliability against flashover, aesthetics, and safety). Poles and towers are designed for structural safety and to minimize cost. Most high-voltage and EHV substation transformers are air insulated. In urban areas, where space is at a premium and air quality is poor, gas-insulated substations are popular. The 30–40% cost premium is easily recouped in land savings, reduced maintenance, and ease of installation. Other emerging transmission technologies that increase efficiency include fault recorders, system control and data acquisition at substations, fibre optics for supervision, control, and protection, and compact high-voltage transmission lines.

Although certain design considerations are universal for transmission of both AC and DC, there are unique features related to HVDC transmission that warrant consideration. Reliable and proven technology exists to transmit HVDC at about 600 kV. The heart of the technology is the convertor at one end of the transmission route to convert from AC to DC and the inverter at the other end to convert it back again. Solid-state thyristors are now used as valves in convertors. These thyristors are modular and can be arranged in parallel or series to give the required valve rating. Recent research suggests that the capacity of thyristors can be increased while costs are decreased. Care must be taken in the design of convertor/transformers to avoid a range of problems created by stressing the equipment simultaneously with AC and DC.

## **Transmission Grids in Developing Countries**

Existing problems with the transmission networks of developing countries must be recognized:

- Networks are weak or have underdesigned portions that lead to system instability or collapse (for example, during an outage of a key substation transformer).
- Grids may be established without sufficient economic criteria, which leads to a large, oversized system that serves areas of insignificant demand.
- It may be difficult to justify connecting large metropolitan load centres that are often served by dispersed generating sites.
- Training and motivation are weak, and many staff lack access to necessary computer controls.

Developing countries should be prepared to take advantage of opportunities to improve the efficiency of their transmission networks. Some recommendations for more efficient execution and operation are the following:

- Where possible, buy equipment locally (for example, use local wooden or concrete poles, oversized conductors, and porcelain or glass insulators).
- Upgrade existing systems with improved technology rather than increase facilities to transmit more power.
- Cut costs in urban areas by using compact transmission lines and in rural areas by increasing spans.
- Plan carefully before incorporating HVDC because this requires extra costs and skilled labour.
- Ignore more expensive niceties current in developed countries (for example, planning for structural aesthetics or reducing audible noise and radio interference) and run lines that follow the most economical routes based solely on engineering criteria.

## **Suggestions for Further Research**

An international research centre for transmission technology integration should be established to

- Adapt available technologies to meet the needs of developing countries by modifying existing equipment or creating specifications for its development, and
- Train personnel for the efficient operation, repair, and maintenance of facilities.

# **Comparative Evaluation of Nuclear Power in Developing Countries**

*Gustav M. Obermair*

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## **Overview**

This paper reviews the technical, economic, and social factors particular to the development of nuclear power in developing countries. The major conclusion is that the nuclear option is not feasible.

## **Analysis**

The feasibility of nuclear power is determined by the types of reactors available, grid size and demand projections.

The three types of reactors are pressurized water reactors (PWRs), boiling water reactors (BWRs), and Canadian deuterium uranium (CANDU) reactors. PWRs are expected to dominate the market and have net capacities between 500 and 1300 MW. Some new reactors have capacities of 200–400 MW, but these are uneconomical compared with generating plants that use fossil fuels.

The capacity of any single generating station should not exceed about 10% of the capacity on the grid. An outage of a larger station could cause the collapse of the entire grid and perhaps damage the station. If it is assumed that 600 MW is the average economic capacity of a single nuclear generator, the total system capacity should be 6–7 GW before the first nuclear station is added.

A review of developing countries, which assumes historical demand patterns and keeps in mind the above restrictions on system capacity, reveals that 6 countries had nuclear power by 1981 and that fewer than 10 other countries will show technical feasibility before the year 2000. The market for nuclear power in developing countries is small.

## **The Economics of Nuclear Energy**

The actual costs of nuclear generation are still hotly debated in industrialized countries despite more than a decade of experience. Using conservative estimates from US sources, a study by the Department of Energy showed that the costs of coal generation were lower in a majority of US regions. Capital costs have more than doubled in real terms in a decade largely because of technical problems, increased safety standards, long approval and construction delays, and increased interest rates.

Economic analysis from industrial countries shows that nuclear power can be competitive if there is a completely developed utility infrastructure, the producer and installer are experienced, and cost estimates for fuel handling are not exceeded. Because conditions in developing countries do not meet these standards, costs have been estimated to be 70–100% higher than in developed nations.

The share of value added by nuclear plants in developing countries is almost zero. Very little, if any, of the equipment can be produced locally, and construction labour must be skilled and imported. Because the real cost of imports has increased by 30–50% in a decade, these imports can weigh heavily on the budget of a developing nation. In broader terms, the large investments required for nuclear power do not make it as flexible an option as less capital-intensive investments in smaller power stations.

## **Other Issues**

The presence of uranium and thorium deposits should not necessarily be viewed as an asset for countries aspiring to nuclear power. PWRs and BWRs require enriched uranium fuel that is currently available



only from France, Russia, and the United States. Enrichment is technically and economically beyond the capabilities of developing countries. Nonenriched fuel for use in the CANDU reactor requires the production of heavy water, a process that is also beyond the means of developing countries.

Nuclear plants present extreme safety risks not often associated with other forms of power generation. Earthquake-prone countries will be forced to overdesign stations, which adds to cost. The risk of war increases the vulnerability of countries with nuclear stations because these stations are likely targets. Above-ground disposal of nuclear waste forces countries to maintain especially high security and safety standards for unspecified periods.

# **Atoms for Peace, Atoms for War, Atoms for Profit**

*Nikhil Desai*

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## **Overview**

This paper reviews worldwide experience with nuclear generation, particularly in the developed countries. Emphasis is placed on economic performance and the dangers of contributions to nuclear proliferation. A gloomy forecast is made of the potential contribution of nuclear generation in the 1990s and beyond. Recommendations are made for developing countries that are interested in exploring the nuclear option.

## **Analysis**

Consumption of the four primary energy sources (oil, coal, gas, and primary electricity) grew much faster than the world average in developing countries during the 1970s. This trend is expected to continue. The contribution of nuclear energy has been small (0.3% of total primary consumption), and it is not expected to play a major role in developing countries in the foreseeable future. Nuclear power has not lived up to projections. For example, in 1975 energy agencies forecast that worldwide nuclear capacity would be 2 600–5 300 GW by the year 2000; by 1983 this projection had been reduced to 576–851 GW. The long-term outlook for nuclear growth is in doubt.

Experience indicates that, especially in developing countries, the claims of favourable economics and exclusive use for peaceful means cannot be substantiated. Construction costs have escalated steadily, and the threat of conventional oil shortages has not materialized. What is more disturbing is the link between nuclear power generation and arms. There has been scant evidence that enrichment or reprocessing technology has spread through unauthorized channels, that a terrorist has gained access to special nuclear material or facilities, or that a civilian energy facility has directly contributed to weapons capability or weapon stockpiles. However, countries have steadily inched toward the development of nuclear weapons. The deployment of nuclear facilities has certainly, at least indirectly, contributed.

Worldwide investments in nuclear power plants up to 1984 were high (about 200 billion USD or 400 billion USD in replacement costs). These costs include not only capital investments but also research, development, and demonstration costs. The “investing” industry is a combination of large business interests and other governmental or quasigovernmental agencies (for example, military and utility interests). These investments have been made despite the fact that operating experience is lacking. Almost 90% of the nuclear electricity ever generated was generated in one decade (1973–1983).

The international market for nuclear power is dominated by the US light water reactor (LWR). This may be because of some astute (although not always accurate) marketing and because of the economies of scale provided by the large US domestic market. The market is further constrained because large reactors are now necessary to achieve economies of scale. The minimum capacity for an economic reactor appears to be 900 MW. There are expectations for economies of scale in large reactors, although experience to date does not back up this hope. Utilities have taken too long to build plants, and during this time inflation and high interest rates have taken their toll. Plants are experiencing increasingly long lead times to startup, and increases in the price of fossil fuels have placed a greater financial burden on utilities. Real costs were expected to increase from 200 USD/kW for plants completed in the late 1960s to

3 500 USD/kW in the latter half of the 1980s. These costs, coupled with poor technical performance, point to a gloomy economic future for nuclear generation. Although capacity factors of 75–85% had been planned, working experience shows that utilities barely average the lower limit and that some countries may experience averages as low as 50 or 33%.

### **The Nuclear Steam Supply System Industry, the Fuel-cycle Industry, and Fast Breeder Reactor Programs**

The nuclear steam supply system (NSSS) industry encompasses the “nuclear” components of the generation system (reactor vessel, steam generators, and all related equipment). The NSSS industry has been dominated by the United States, although British, Canadian, French, German, Swedish, and recently Russian technologies have been making inroads. However, national and international markets are constrained, and few orders are expected in the coming years. No orders were placed between 1978 and 1984, and as many as 119 plants were cancelled between 1974 and 1983. In the United States and elsewhere, vendors have been faced with declining domestic markets. This has created a stronger interest in export markets. The response from developing countries has not been great because of weak market positions and restrictions on the transfer of certain technologies. Only eight units were ordered by developing countries between 1976 and 1984. Of these, six were from Korea. Other than the US vendors, no other vendors have sold a repeat round of nuclear plants. It is expected that the NSSS market will be characterized by retrenchment and consolidation, a loss of US dominance, and a weakening of the international nonproliferation regime.

The fuel-cycle industry can be divided into uranium mining and conversion, fuel enrichment and fabrication, and spent-fuel management. There are eight leading uranium producers in the world, and the United States predominates. Of developing countries, only Gabon, Namibia, and Niger are producers of note, and all their uranium is produced for export. The supply market for uranium is

characterized by soft prices, declining growth in sales, and a world surplus of enriched fuel.

Reprocessing of spent fuel is at a standstill because of the depressed price of uranium. Reprocessed fuel can be used in converter power reactors or in fast breeder reactors (FBRs). Unfortunately, FBR programs in the United States have been cancelled, and in France and Germany they have been slowed drastically because of operating difficulties. The management of spent fuel is therefore becoming a growing problem, and safe disposal is certain to be a major issue by the turn of the century. Further implications for the industry are that the mining and milling industry will go through a phase of retrenchment and consolidation, the US share of the enrichment market will decline, and countries will have to reexamine high-level waste-handling strategies.

## **Economic Analysis of Nuclear Energy**

The accounting of costs and benefits for nuclear energy should not be the same as for other forms of electricity generation. This is because of the possibilities of severe accidents, accidental exposures at all levels of the fuel cycle for centuries, and the manufacture of weapons. As well as these uncertainties, there are the unknown costs of decommissioning and permanent disposal of generation facilities and of the disposal of spent fuel.

It is difficult to estimate accurately the full costs of nuclear generation because of the industry's secretive nature and the variations in accounting procedures and subsidies between nations. Capital costs are the major component of nuclear generation costs (between 50 and 90%) compared with electricity generation with fossil fuels (between 25 and 50%). This heavy capital weighting makes total costs vulnerable to real escalation during construction and to financing costs. Because nuclear generation has a high proportion of "sunk" costs, the cost of power is much more sensitive to capacity factors than that of other fuel sources. The performance of nuclear plants has not been encouraging; therefore, it is unlikely that nuclear plants can compete with coal-fired generation.

An economic comparison of nuclear and coal plants (under varying discount rates and capacity factors) showed that capital costs per kilowatt (1985) for nuclear power varied from 2 000 to 2 835 USD, whereas costs per kilowatt for coal plants varied from 1 200 to 1 400 USD. If variations in plant life and escalations in the cost of coal are taken into account, unit energy costs for nuclear power compare favourably with those for coal only under conditions of a low discount rate and high capacity.

The experiences with the LWR in the United States provide the largest body of long-term data in the world. Comparison of these experiences shows that there are tremendous variations in cost and performance that are not readily explained by any one circumstance. Capital cost per kilowatt ranged from 1 871 to 6 134 USD (1983), construction time from 71 to 187 months, and concrete requirements per megawatt from 106 to 450 m<sup>3</sup>. These same variations can be expected in developing countries.

Given the greater uncertainties associated with the nuclear option and the costly experience of developing countries (for example, Argentina, Brazil, Iran, Mexico, and the Philippines), for most developing countries today, the promise of “atoms for profit” is no longer real.

## **Suggestions for Further Research**

Slow expansion of nuclear generation might be expected beyond the 1990s if operating performance is improved, methods are found to decrease capital costs without sacrificing safety, costs of nonnuclear fuel show long-term real growth, and the problem of high-level waste disposal is solved.

Before they make investments, developing countries should wait until the costs and performance of generation technology are stabilized and the global nuclear industry is restructured to provide a strong institutional base for in-country development.

Research is required on

- Case histories of decision-making processes in developing countries, using a common analytic approach that would

identify the decisions that were taken and the alternatives that were investigated,

- Construction and operating experiences in developing countries to gather data that will help others to make decisions about economic feasibility, and
- The experience of developing countries with technology transfer to determine how these countries have “unpackaged” the technology and what the prospects and precursors are for the development of manufacturing and regulatory capabilities.

**Volume 5**

**Oil and Gas**

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*Volume editor: Zhu Yajie*



# **Analyzing the Prospects for Exploration and Development**

*D.C. Ion*

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## **Overview**

Exploration for and development of oil and gas are fraught with considerable risk and uncertainty. Although developing countries harbour significant proportions of the world's oil and gas reserves, they face substantial technical challenges in realizing the development of their indigenous resources. Fortunately, solutions are available, and with the appropriate knowledge, expertise, and international support, developing countries can optimize resource development. However, the key is to access these technical solutions in a manner that ensures that clearly set domestic objectives, which satisfy the needs of the people, are met.

## **Analysis**

There is substantial interest in exploration for and development of petroleum resources (both oil and gas) in developing countries. Excluding the (former) communist countries, the non-OPEC (Organization of Petroleum Exporting Countries) developing countries harbour about 10% of the demonstrated reserves of crude oil and an estimated 26% of the undiscovered recoverable natural gas in the world. In 1976, a few years into the energy crisis, oil companies were active in 71 non-OPEC developing countries. By the early

1980s, the industry was quite active all over the world and was expanding into the South Pacific, Western Asia, sub-Saharan Africa, Central and South America, and the Far East. China in particular was a centre of attraction.

## **Technical Challenges and Solutions**

The first challenge is to isolate the likely conditions under which petroleum was originally formed and subsequently migrated. Because of its viscous nature and the porous nature of subsurface strata, it is not unusual for petroleum to migrate hundreds of kilometres before it becomes trapped. Sophisticated mathematical models have been constructed over the past 10 years to describe this behaviour, and they have assisted in the identification of likely petroleum sites. Complex geological surveys and analyses also contribute to our understanding of petroleum formation and accumulation.

Additional challenges arise when the petroleum is produced. Conventional production methods at best produce no more than 30% of the oil in place. Enhanced methods of oil recovery that use water, solvents, steam, or other agents can significantly increase these recovery rates.

Other challenges associated with the full-cycle development of resources can be successfully addressed by new technical developments. Aerial surveys, remote sensing, radioactivity surveys, and computer-based image processing all assist exploration activity. Sonic logs, radioactivity logs, and advanced methods of coring provide important insights into optimal reservoir development. Directional drilling technologies have contributed to lower-cost operations, improved recovery, and decreased disturbance of the environment.

## **Inherent Uncertainty and Risk**

Although technology has been steadily improving, exploration and development are subject to significant exploration uncertainty and production risk. Likely areas for exploration may hold water instead of hydrocarbons, or if there is oil present, it may be of a quality or

quantity that does not warrant commercial development. Daily production from wells may range from as low as 10 barrels to as high as 20 000 barrels (1 barrel = 0.16 m<sup>3</sup>). Exploration costs for drilling also vary tremendously (for example, a single well on the Alaska North Slope cost 130 million USD to drill). Economic uncertainty (because of price fluctuations) poses a particular risk for developing even well- delineated deposits of oil shales or oil sands. These heavy oils rely on sophisticated extraction techniques that themselves require a great deal of energy. Even if oil prices rise, the commercial feasibility of these prospects may not be improved because of the energy needed to produce the oil.

## **Accessing Technology to Optimize Prospects**

A major challenge for any developing country is to gain access to the technology that is capable of finding and producing the hydrocarbons, while minimizing the degree of risk exposure. Up-to-date technological expertise is often absent in developing countries, and most approaches to exploration and development have relied on various cooperative arrangements with outside organizations or industries. The most successful approaches have been those that relied on either a risk-sharing agreement or a strict nonrisk technical services contract. Long-term concessions for petroleum development are no longer common. Important aspects of any of the these approaches include a delineation system or grid to define tenure, an incentive framework that provides operators with adequate financial incentives to look for and develop the resource, a regulatory system that is consistent with the operating customs and practices of the industry, and a business and institutional arrangement in which confidentiality of information can be ensured. These factors have contributed to successful exploration and development programs in developing countries.

## **Role of Local Expertise**

Local experts play an important function in providing an assessment of domestic needs and priorities, although to be effective these

people must also have a sound understanding of the technical conditions and risks. Furthermore, to ensure that a receptive environment is established for technology transfer and resource development, the local experts must understand the needs of the industry. An effective way to achieve this is to conduct in-country modeling and forecasting exercises to identify priorities and options in the energy sector. This provides a basis both for developing expertise and for energy planning.

### **Suggestions for Further Research**

To ensure that developing countries can exploit their indigenous petroleum resources (both crude oil and natural gas), additional research support is urgently needed at the local level. In any given country, this research support should concentrate on

- The development of local programs to establish a team with adequate technical expertise to monitor the work of hired specialists, and
- The development of a model of future long-term energy needs that places domestic options in a global context, allows for regular monitoring, and provides some mechanism to assist with decisions about energy.

# **Ensuring Exploration and Production in Developing Countries**

*R.J.P. Ross*

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## **Overview**

Continued exploration for and production of oil and gas in developing countries are constrained by the fundamentally different perspectives of the governments of these countries and the transnational corporations that are engaged in the oil and gas sector. The objectives of governments focus on domestic concerns, whereas the objectives of industry focus on corporate profitability in a global setting. Governments are often constrained by a limited number of development options, whereas industry has the flexibility to invest in different parts of the world under potentially quite different regimes. These factors contribute to the markedly different strategies that governments and industries might have for oil and gas exploration and production. Reconciling these strategies requires careful cooperation between industries and governments. In many circumstances, it must be recognized that the strategies are so divergent that there is inadequate common ground for working together. To address these circumstances, alternative institutions are required to ensure that feasible oil and gas prospects are discovered and developed in developing countries. For example, a company might be established explicitly to explore for and produce hydrocarbons in developing countries and to concentrate on opportunities currently being neglected by transnationals.

## **Analysis**

National governments and transnational corporations have quite different objectives in the exploration and production of petroleum. Governments require technical programs that can delineate the detailed extent and producibility of their resource base and pay attention not only to large-scale oil potential but also to small deposits and to natural gas. Transnationals, because of the diversity of global prospects, require a more general assessment of exploration potential and risk to establish whether a region warrants additional investment compared with options elsewhere. Transnationals concentrate on large-scale oil potential, and natural gas is usually not the primary target because of its limited marketability. Governments require commercial arrangements that provide adequate financing and transfer the risk to an external operator, but they do not give up control over the rate of development of the resource. Transnationals, on the other hand, require arrangements that provide expected financial rewards under fiscal, legislative, pricing, and production-sharing regimes that are comparable with those available elsewhere. Governments require that local personnel be trained, that local industry be developed, and that technology and information be transferred. Transnationals are often concerned with the confidentiality of information and technology and with their freedom to make decisions that would increase the operational success of the venture. Finally, governments are often concerned with ancillary objectives (for example, environmental impacts or conflicts between different sectors of development).

### **Limited Choices**

In contrast to the many objectives that the government of a developing country might have, its available options for developing the resource are quite limited. Self-reliance is difficult even for the richest of nations. Reliance on foreign assistance is too often tied to the use of technologies that may not be appropriate. The development of a national oil company is not a realistic short-term option for most developing countries that do not already have one. Complete reliance

on transnational corporations creates problems if the country does not have the means to attract and retain these companies in the first place.

## **Divergent Strategies**

Because of these different objectives and constraints, governments and industries will typically adopt different strategies for exploration and development. To supply local markets or obtain hard currency from exports, the government will want to use whatever technology is available to recover the resource (however small). Industrial strategies, in contrast, will concentrate on using tried, tested, and trusted technologies to find and develop large prospects with readily marketable products. Different strategies for technology transfer, training, and information transfer will also be adopted. Governments often see these transfers as a source of power or wealth, but some experiences have shown that the transfer of inappropriate technology or the misuse of proprietary data can lead to further conflicts. These transfers should only be conducted if it can be demonstrated that the technology can be used and that the transfers realistically take into account the learning curve of 2–5 years that is often required.

## **Role of an Alternative Institution**

If objectives, options, and strategies diverge so considerably, how can a developing country develop its modest hydrocarbon potential if it cannot attract and retain industry's interest? A cooperative, regional, or alternative institution could provide an appropriate mechanism. The role of the institution would be to assess when and how to use transnational corporations, to cooperate with several transnationals in certain ventures, to use medium-size oil companies as appropriate, to retain land, to structure arrangements to ensure appropriate technology transfer, and to meet local employment and industrial objectives. Tasks that such an institution would need to fulfill include exploration and development, marketing, provision of information about transnationals, local sourcing, financing, and research. Adequate financing of such a venture would be required to

ensure flexibility and credibility and would best be sought from developing countries and from organizations that assist with development. To ensure its success, this type of institution would have to focus on South–South cooperation and continue to search for alternatives.

## **Suggestions for Further Research**

To ensure that exploration for and production of reserves in developing countries proceed effectively, additional research needs to be undertaken to

- Develop methods to stimulate exploration and production in the Third World, especially in oil-importing developing countries,
- Enumerate the activities of transnational companies to identify the types of activities that are currently being left out and that might profitably be pursued by an alternative institution,
- Assess the feasibility of establishing a company that would explore for, and produce, 10–20 of the best opportunities that are currently being neglected by transnationals (gas and small deposits of oil would be accepted as good candidates), and
- Assess the feasibility of establishing a technology centre that would emphasize technology transfer, funding, and commercial applications.



# **Exploiting Reserves of Natural Gas**

*Glenn W. Mortimer*

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## **Overview**

Domestic reserves of natural gas are a potentially important resource in many developing countries. As reserves of crude oil are depleted and global demand for energy continues to increase, natural gas will be viewed increasingly as a substitute. However, these gas reserves pose special challenges because the commercial feasibility of any development of natural gas is often inextricably tied to the identification and capture of specific markets. Traditional markets for natural gas include domestic uses (power generation, industry, and space and water heating) and exports as liquefied natural gas (LNG) or as a feedstock for ammonia and urea. Developing countries can benefit from new market opportunities for natural gas as a transportation fuel and as an input in methanol production. Methanol has applications as a chemical product, a fuel additive, and an input to the manufacture of protein substitutes. If developing countries are to realize any of these new market opportunities or are to build on traditional markets, they will require knowledge and expertise to develop coherent supply strategies and policies for natural gas.

## **Analysis**

Annual trade in natural gas is about 100 billion to 200 billion USD. However, natural gas has generally been regarded as a less desirable exploration or development target than crude oil. The collection,

transportation, treatment, and distribution of crude oil and refined products are much cheaper than for natural gas on an equivalent heating basis. In addition, because much of the institutional structure is focused on solid and liquid fuels, conversion to natural gas can add further costs. Investments in natural gas infrastructure (pipelines, distribution systems, and liquefaction and regasification terminals) are substantial, and because it has very little flexibility after it is constructed, it can normally be justified only when a market has been established. In most developing countries, these challenges hinder gas development. Although potential reserves may be large, domestic markets may be inadequate to provide the required incentive to develop the gas. A key to successful exploitation of gas reserves is to focus on market development.

## **Development of Traditional Domestic Markets**

Traditional domestic markets for natural gas rely on extensive uses in power generation, industry, and the commercial and residential sectors. Gas can be used in steam turbines, combustion turbines, or diesel units to generate electric power, and it can also be used in the overall power system to balance and optimize the loads from hydroelectric and thermally generated electricity. An attractive feature of gas-fuelled units is that they can be added relatively quickly and economically in small increments. Natural gas can also be used in most industrial applications that currently rely on coal or refined petroleum products. Conversion is technically straightforward, and after completion, the equipment accommodates multifuel use, which gives operators greater flexibility in the choice of fuels. In the residential and commercial sectors in developing countries, the most common applications for natural gas are for water heating and cooking (and for space heating in cooler climates). A major constraint to successful market penetration in the residential sector is that the poor (who are typically in the majority) cannot afford the modest capital outlay required to purchase gas burners. Subsidies for the gas or equipment have often been provided as an incentive to use gas.

## **Development of Traditional Export Markets**

A traditional activity for developing countries is to export natural gas as LNG or to use it as a petrochemical feedstock to produce ammonia and fertilizers (for example, urea). LNG projects liquefy the gas, ship it through a cryogenic LNG terminal to a source where it is regasified, and then distribute it through conventional distribution systems for gas. About 20% of the global gas trade is LNG, but the feasibility of this trade relies on long-term commitments and contracts of 15–20 years. These arrangements underline the importance of establishing the existence of adequate reserves to meet the long-term obligations and of having low-cost gas available at the point of liquefaction to ensure that the project is commercially feasible. In contrast, ammonia or fertilizer exports are attractive because they are not tied to any single consumer and can be directed to a number of markets. Demand for these products grows as agricultural output grows, but the feasibility of any project depends on global demand and the availability of low-cost gas.

## **New Market Opportunities**

New market opportunities are associated with natural gas as a transportation fuel and with the demand for methanol, which is produced from natural gas. Propane or compressed natural gas (CNG) can be used as a transportation fuel in engines that currently operate on gasoline. Its advantages are that it is cheaper than gasoline, less corrosive, and safer. Its disadvantages include storage problems, reduced power, and significant capital outlay for vehicle conversion. Methanol has a number of applications that provide important prospects for new markets. Its major chemical use is the production of formaldehyde, which is used primarily in the manufacture of resins and paints. As a fuel, methanol can be used directly in gasoline, diesel, or natural gas engines or boilers, upgraded to methyl tertiary butyl ether (MTBE) as a gasoline blending agent, slurried with coal, or upgraded to a synthetic gasoline. Some of these technologies are well developed, whereas others are still experimental. Finally,

methanol has a potential food use when used to manufacture single-cell proteins (SCP). Commercial projects do exist to market SCP as an alternative to soybean meal and fish meal for animal feed.

### **Realizing the Opportunities in Developing Countries**

The development of projects to take advantage of growth in traditional markets or to penetrate new markets will require considerable expertise and planning. Supply planning must be oriented to ensure that tax and royalty terms, joint ventures, production-sharing agreements, and service contracts encourage exploration for natural gas. Local knowledge and expertise must be developed so that policies for natural gas that account for both domestic needs and export opportunities can be formulated. Local capabilities are also needed in techniques of project valuation to assess the feasibility and risks of any natural gas development.

### **Suggestions for Further Research**

To ensure that reserves of natural gas are exploited optimally in developing countries, additional work needs to be undertaken to

- Develop an educational program (on alternative production, transportation, and utilization technologies for natural gas) that is directed both to developing countries and to organizations that advise them,
- Establish, in developing countries, demonstration projects that use unconventional approaches to the production, transportation, and utilization of natural gas,
- Concentrate research on small-scale liquefaction of natural gas and methanol production, and
- Concentrate research on the development of vehicles that can use methanol and natural gas.



**Volume 6**

**Alternative Liquid Fuels**

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*Volume editor: José Goldemberg*

# **Alternative Fuels: A Brazilian Outlook**

*José R. Moreira and Gil E. Serra*

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## **Overview**

This paper reviews the production of alternative liquid fuels in Brazil. The economics of biomass cultivation and of fuel production is examined. A careful costing is made of all operations involved in the biomass crops (wood, sugarcane, and cassava). Industrial conversion technologies, market analysis of liquid fuels, and displacement of conventional energy are also analyzed. The paper concludes with a discussion of institutional problems and draws conclusions about the future of biomass as an alternative energy source.

## **Analysis**

### **Biomass Crops**

**Wood** — Because of increased consumption and export of wood, the Brazilian government began to offer fiscal incentives to stimulate reforestation in the 1960s. In the 1970s, the use of financial resources improved as better technology was introduced and forests were restocked with selected foreign species, mainly rapid-growing eucalyptus and pine.

Eucalyptus is more suitable than pine for energy production because it provides a quicker return on investment, has denser wood, and is more easily harvested. Impressive gains in productivity have been achieved from genetic breeding. Eucalyptus traditionally

reaches harvest age in 7 years. The total production cost for 1 ha of planted eucalyptus forest over 21 years, the time commonly required for three harvests, is 1 274 USD. This assumes an opportunity cost of capital of 10%, a tax incentive of 200 USD/ha, and yields of 175 m<sup>3</sup> in the first and second harvests and 137.5 m<sup>3</sup> in the third harvest. The crop is already economical by the second harvest at a price of 1.88 USD and shows a profit at 2.19 USD. This suggests that tax incentives may not be necessary, but their existence is justified by the 7-year wait between the initial investment and the first returns. Because of the 25-year span between planting and first harvesting of pine, this species cannot compete with eucalyptus as an energy crop.

**Sugarcane** — Because sugarcane represents about 60% of the cost of ethanol production, the success of a sugarcane-based program of ethanol production depends on sugarcane productivity. Annual productivity varies greatly in Brazil (from 50 to 150 t/ha; national average 53 t/ha). It is common to obtain four harvests in 5 years. The National Alcohol Programme increased investment in sugarcane cultivation and led to significant increases in cane productivity and quality. A program for sugarcane breeding seeks to obtain new and improved varieties. For maximum productivity, the sugarcane grower should harvest the sugarcane when it reaches its period of maximum growth.

Processors normally use better technology and achieve higher sugarcane productivity than independent growers. The custom, in most developing countries, is to pay for a crop by weight and to make minimal quality stipulations. In 1984, Brazil established a payment system based on sucrose content to improve quality and increase profits from ethanol and sugar manufacture. Although the sugarcane industry is flexible in the substitution of mechanization for labour, several operations, in particular cane harvesting, are manual. The employment of seasonal labour for the harvest is still common, but there is a tendency for mills to maintain a full-time labour force.

With the improvements in sugarcane productivity and quality, it is possible to obtain yields of 120 t/ha for plant cane and 95, 80, and 70 t/ha for the three subsequent ratoon crops. If it is assumed that



these yields are obtained and that the annual interest rate is 10%, the total costs for the cultivation of 1 ha of plant cane would be 1 022 USD and the total costs for 1 ha of ratoon cane (yield 80 t) would be about 454 USD. Therefore, sugarcane sold at the market price in July 1984 (8.40 USD/t) should have yielded a profit. The exploitation cost of sugarcane was 7.40 USD/t.

**Cassava** — Cassava is produced for human and animal consumption generally by subsistence cultivation and without technological improvements. Although four new cassava distilleries were built in Brazil in the early 1980s, they have faced a shortage of raw materials. The cassava plantations have failed because of the overestimation of the ability of cassava to thrive on poor soil and the absence of large, established plantations and intensive production.

For human consumption, cassava is harvested at the end of one vegetative cycle (8–12 months). For industrial use (to produce starch or ethanol), it is harvested at the end of two cycles (15–24 months) when the starch content is sufficiently high (27% is considered a reasonable average). Most planting and harvesting are manual, but some mechanized planters and harvesters are being introduced. Based on production of 20 t/ha, cassava was a profitable crop at the July 1984 market price of 45 USD/t (the break-even point was 35 USD/t).

**Other** — Nontraditional crops for ethanol production are sweet sorghum, corn, sweet potatoes, and Jerusalem artichokes.

## Industrial Processing

**Wood** — The commercial processes of combustion use wood as a substitute for petroleum or gas to produce heat, steam, or electricity. The thermochemical processes of pyrolysis, gasification, and saccharification and fermentation are not yet commercial. These processes attempt to use wood for the synthesis of various products that are designed as fuels for boilers, kilns, and internal combustion motors.

The direct combustion of wood to produce heat or steam has an efficiency of 68%. Predrying and powdering of wood help to improve boiler efficiency. Brazil built more than 500 boilers for steam production as part of its National Alcohol Programme. The cost of these boilers is substantially lower than in North America. Cost analyses revealed that these low-pressure boilers were significantly cheaper than high-pressure boilers, possibly because of the mass production required for the alcohol industry.

**Sugarcane** — Cogeneration systems appeal to electricity planners because it may be feasible, given the complementary rainfall cycle and cane harvesting season, to cogenerate electricity from hydroelectric and sugarcane-bagasse thermoelectric plants. Although cogeneration is not appropriate for all applications, it is becoming more economical, and large, new electrical utilities are becoming more costly. In Brazil, the cost of cogeneration plants is favourable relative to the North American market.

**Charcoal** — Almost all (90%) of Brazil's significant charcoal production is used to produce pig iron. Charcoal represents 65% of the cost of pig iron. Charcoal contains only 42% of the energy of the crop in the field. The two objectives of efforts to improve the carbonization process are to increase the proportion of energy recovered from the available biomass and to improve the profitability of the productive sector. As a result, the wood-charcoal conversion index is improving. Florestal Acesita SA, a large charcoal producer, has established a technology-development program to obtain wood carbonization by-products for use in chemical products and medium-energy liquid fuels. Ways are also being sought to reduce the amount of charcoal used in the new processes that are being developed to produce pig iron.

**Wood Gasification** — The most primitive wood gasification technique yields producer gas, which has a low heat value that increases its transportation costs and inhibits flame temperature. In addition, the impurities in the gas cause obstructions in pipelines. However, producer gas has a major possible use as a fuel for con-

verted stationary engines, and it may be possible to convert vehicles to run on the gas.

Medium-energy producer gas can be manufactured by eliminating nitrogen from the gas product. This gas can be used for combustion with high flame temperatures and for the synthesis of hydrogen, methanol, and other alcohols. However, methanol production from wood gasification is still experimental.

**Ethanol from Wood** — The only effective industrial process for ethanol production from wood uses sulfuric acid. Commercialization and dissemination of this technology have been limited. In Brazil, this process is still at the testing stage. Further study is required to deal with corrosion and scale formation. Cost analysis of a plant that produces ethanol from wood has revealed that ethanol production by hydrolysis is not feasible unless the cost of production can be reduced significantly.

**Ethanol and Sugarcane** — In more than 95% of Brazilian distilleries, the stages of production of ethanol from sugarcane are milling of whole and burnt stalks, batch fermentation with yeast recycling, and distillation in stainless steel columns under low pressure. Each stage could be improved by technological innovations. For example, the sugar concentration in the juice could be adjusted to optimize fermentation and distillation, the fermentation temperature could be maintained at about 32°C to better control fermentation, and perforated trays could be used to promote greater efficiency and lower the costs of distillation. If standard sugarcane at appropriate operating efficiencies yields 73 L of fuel ethanol per tonne, a sugarcane plant that produced 120 000 L of ethanol a day would make a profit of 0.028 USD/L.

**Ethanol from Cassava** — None of the cassava distilleries built in Brazil in the early 1980s is in continuous operation or working at capacity. The industrial process is almost fully developed except for the difficulty of separating cassava fibres, which leads to a 10% loss of ethanol. Difficulties in the industrial process can be attributed to unconventional technology in secondary steps.

Preliminary cassava treatment covers reception, cleaning, peeling, cutting, and grating. The hydrolysis stage involves dextrinization and saccharification and is followed by fermentation and distillation. A cost analysis of cassava plants that yielded 120 000 L of ethanol a day revealed that cost reductions of 0.08–0.09 USD/L were needed to make ethanol production from cassava feasible. If the plant operated for 140 days a year using dried root chips and 160 days using fresh cassava roots, the operating costs almost doubled. Because 75% of the cost of ethanol is raw materials, economic feasibility could be achieved by higher crop yields.

### **Market for Alternative Fuels**

Because of the structure of energy prices in Brazil, the lowest risk for alcohol marketing, at the beginning of the National Alcohol Programme, was as a gasoline alternative. Alcohol was initially introduced in a gasoline–ethanol blend and, eventually, as a total substitute for gasoline. After the initial euphoria surrounding the introduction of ethanol-powered vehicles, the market reacted unfavourably because of the poor quality of the motors. Car manufacturers were unwilling to make the necessary modification, and uncontrolled workshops were doing substandard conversions. Intense consumer reaction led the government and vehicle manufacturers to improve product quality and to offer economic advantages to buyers. Since 1983, more than 80% of the market for new cars has been ethanol-powered vehicles.

The use of ethanol as a substitute for diesel fuel is mainly an economic problem that could be solved by adding ethanol to the diesel fuel, designing engines with double injection systems, using glow-plugs, or replacing diesel engines with Otto-cycle engines. Because diesel fuel and ethanol are about the same price per litre, widespread use of ethanol as a substitute for diesel fuel is limited.

The operational cost of wood for steam generation is competitive with the cost of fuel oils. However, the use of wood is limited by the noncompatibility of wood with oil furnaces, the absence of forests in the areas where the wood is required, and the difficulties associated with large areas to hold firewood in densely populated zones.

The first problem can be solved by replacing oil furnaces with firewood furnaces. The transportation of wood over greater distances can be made more economical by relying on less expensive transportation or by transforming the wood into a product with a higher energy content per kilogram (for example, charcoal). Similarly, the problem of local storage can be reduced if the wood is made into briquettes.

Hydroelectricity, although economical only for high-load power requirements, can compete with biomass principally in densely inhabited, industrial areas. Competition is also possible in other areas, especially during the rainy season. To completely eliminate oil from the pulp and paper process, oil must be replaced with electricity, which could be cogenerated by hydroelectric and biomass-based thermoelectric plants.

### **Requirements for the Use of Biofuel Technologies**

The original interest in alternative fuels was to reduce the costs of imported energy in developing countries. When the price of oil soared in 1973, the implementation of alternative energy programs became more difficult to justify. Therefore, Brazil's National Alcohol Programme, which was based on simple technology and low investments, cannot be easily transplanted to other developing countries.

### **Suggestions for Further Research**

If real oil prices remain constant, technology in alternative energy programs must be optimized. Competition must be maintained by making biomass technologies available to several enterprises, and technological improvements should be concentrated on low-efficiency processes. In addition, it is suggested that

- It is more important to determine the production methods and cost criteria for a new energy source than to define precisely where and how the source will be used,

- Government agencies responsible for various energy sources be subordinate to an overall energy policy, and
- The introduction of biofuel technology in the least developed countries start with simple uses (for example, direct use of wood for heat and steam) because most developing countries lack sophisticated technology.

# **Alternative Transport Fuels: Supply, Consumption, and Conservation**

*Sergio C. Trindade*

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## **Overview**

This paper concentrates on energy conservation and on a range of alternative transportation fuels. Alcohol fuels (ethanol and methanol), gaseous fuels (natural gas and LPG), and “other fuels” (producer gas and vegetable oils) are considered. A standard analysis is employed that consists of the use of these fuels in Otto or diesel engines; their production, distribution, storage, and transmission; the economics of their use; and a preliminary ranking of their research and development (R&D) needs.

The importance of taking an integrated systems approach to analyzing transportation services is emphasized. Planning and policy are reviewed to identify and rank priorities in technical, economic, and policy research areas.

## **Analysis**

The analysis of alternative fuel systems for transportation varies greatly from country to country; however, there is a global requirement for conservation and interfuel substitution through improved vehicle and system efficiency and better planning and policies. Therefore, R&D efforts toward such global requirements should receive the highest priority. R&D on natural gas should also be given

high priority, whereas R&D on alcohol fuels and LPG should only be given intermediate priority. The lowest priority should be assigned to producer gas and vegetable oils.

## **Alcohol Fuels**

The alcohol fuels (ethanol and methanol) are potentially abundant and can be produced from a variety of raw materials. In addition, they are more compatible with traditional fuels than other alternatives.

**Ethanol** — Ethanol, which has a greater energy efficiency than gasoline in Otto engines, can be blended with gasoline or used as a neat fuel. When used alone, some adjustments are necessary. These adjustments can be easily accomplished by trained mechanics, or vehicles can be manufactured to burn ethanol. To use ethanol in diesel engines, measures must be taken to improve ignition, modify the engine, install dual-fuel systems, or convert the engine to Otto cycle.

Brazil's program in alternative fuels for transportation is the largest in the world and is based on sugarcane-derived ethanol. The program relies on the existing infrastructure for petroleum fuels to distribute, store, and transport ethanol. The phase-out of premium gasoline has allowed ethanol to take its place. Anhydrous ethanol, derived from ethylene hydration by the petrochemical industry, acts as a buffer to ensure an adequate supply of ethanol. Alternative substrates for ethanol production include cassava and wood. Although there is considerable interest in these alternatives, both are at the demonstration stage. Ethanol can be demonstrated to be economically competitive with diesel, particularly for trucking. Further economic analysis is required that compares the true costs, stripped of taxes and subsidies.

R&D priority should be given to the investigation of the most promising biomass materials for conversion to ethanol, the optimization of alcohol content in gasoline blends for Otto engines, and the adaptation of Otto engines for use with ethanol.



**Methanol** — The discussion on methanol parallels that on ethanol. Conversion requirements for Otto and diesel engines are similar. Some limitations of methanol include a low water tolerance in gasoline blends, high vapour pressure, low volumetric energy relative to gasoline, engine lubrication problems, and toxicity. Markets are developing in Europe and the United States for methanol, particularly as an octane enhancer. Because of global overcapacity, methanol is selling at very competitive prices compared with gasoline. This alcohol is expected to eventually outstrip ethanol because of its wider diversity of raw materials, the value added to natural gas when it is converted to methanol for transportation purposes, and its lower costs. To make methanol, a synthesis gas (which varies with the type of feedstock) is first produced. Currently, the cheapest methanol is made from natural gas, but synthesis gas can also be derived from coal or wood, although these latter processes are presently uneconomical. R&D priorities are similar to those for ethanol.

## **Gaseous Fuels**

Gaseous fuels are defined as natural gas (including CNG and LNG) and LPG. The use of these fuels is growing as more natural gas reserves are discovered, particularly in developing countries. The major disadvantage of these fuels is that they are gaseous at ambient temperature and pressure. As a result, the storage system for the gas limits its use as a transportation fuel. Gaseous fuels give good performance in Otto engines because of their high octane rating; however, because distribution systems are not widespread, a dual-fuel approach for Otto engines is common. This approach requires a compromise that is not the best for either fuel and fails to take advantage of the high octane rating. Because gaseous fuels have a low cetane number, their direct use in diesel engines is limited. Measures to improve ignition, similar to those discussed for ethanol, are required.

**Natural Gas** — Natural gas is composed mainly of methane and is found either with petroleum or in isolated reservoirs. Methane can also be obtained through biomethanation, a process that is becoming

more widespread throughout the developing world. However, only large biomethanation plants can produce methanol at a cost that makes it competitive with conventional fuels in the same market (although this may change in the future).

Italy has the world's most developed program to use natural gas as a fuel. Natural gas is distributed through pipeline networks or in tube trailers pulled by trucks. The benefits of natural gas depend on the value of the fuel that is displaced. Natural gas competes very well with gasoline as a transportation fuel. The priorities for R&D are to adapt existing natural gas systems to local conditions for Otto engines and to develop new on-board storage systems for Otto engines.

**Liquefied Petroleum Gas** — LPG is either obtained from petroleum refining or separated from reserves of natural gas. In countries that have no reserves of natural gas, it is marketed as a household fuel. Because there is a greater incentive to use LPG as a transportation fuel in countries endowed with natural gas, LPG is not expected to be a major alternative fuel in the long term. LPG can be transported by pipeline, truck, rail, and barge. Under appropriate conditions, it can be very competitive with gasoline as a fuel for vehicles. The highest R&D priority is to adapt existing LPG systems to local conditions for Otto and diesel engines.

## **Other Fuels**

**Producer Gas** — Producer gas has a high octane rating and can be used in Otto engines; however, because of its low energy density it is characterized by high power loss (up to 50%) compared with gasoline. Diesel engines can operate with producer gas if they are converted to Otto cycle or fed diesel oil and producer gas simultaneously. The main limitation of producer gas as a transportation fuel is the need to carry an extra load in the form of a gas generator and primary fuel. Because producer fuel cannot be stored, issues of distribution and storage relate to the primary fuel. The production of producer gas requires a generator, a filter, a cooler, a mixer, and a throttler. Generators for producer gas are not widely available and require an investment of about 2 000 USD. There appears to be a

limited market for this fuel as a transportation fuel except for local or contingency situations. R&D could be directed toward decreasing the loss of engine power and mitigating the environmental impact of emissions, which are rich in carbon monoxide.

**Vegetable Oils** — Vegetable oils are more expensive than diesel oil and they neither aspirate nor vaporize well in the Otto engine carburetor because of their high viscosity and low volatility. Therefore, they appear to be poor alternatives for diesel fuel or gasoline. The use of vegetable oils causes serious deterioration of engine performance over time. Consequently, modifications of vegetable oils (for example, transesterification with methanol or ethanol and thermocatalytic cracking) have been proposed. Various blends of transesterified or natural vegetable oils with diesel oil and with alcohol are characterized by performance difficulties. Transesterified vegetable oils give reasonable performance but cost more. Data on cracked oils are limited. R&D initiatives will probably continue to hedge against growing fears of middle distillate shortages in specific countries.

## **Transportation Systems**

Transportation services should be analyzed with an integrated systems approach in which alternative fuels and energy conservation play a limited but important role. Often, the analysis of energy intensity ignores the total energy used by a specific mode of transportation. It is useful to distinguish between energy intensiveness, line-haul energy (the energy required to operate the infrastructure to maintain the transportation system), modal energy (line-haul energy plus the energy for access), and program energy (the total expected energy consequences of the transportation system). Passenger transport energy (PTE) can be computed by adding travel demand, the reciprocal of load factor, and vehicle energy intensity across all types of fuels and modes of transportation. A comparison of energy intensities of various modes of passenger transportation reveals that air transportation had the highest energy intensity, followed by private automobile, rail, and bus. Freight transport energy (FTE) can be

calculated in a similar manner. FTE and PTE are useful tools for measuring systems efficiency. It is instructive to note that vehicle energy efficiency affects only one of the three terms in the calculation of system energy efficiency.

Economic studies of energy demand suggest that the short-term price elasticity of demand for petroleum products is relatively low and that income elasticities among developing countries vary more than price elasticities. Therefore, short-run, price-inelastic demand for transportation energy is not conducive to immediate measures of energy conservation in response to higher prices. Also, because the cost of freight transportation usually accounts for a small fraction of total production cost, higher energy prices will not result in a large contraction in the use of transportation energy. Although energy conservation plays a limited role, any concept of systems management must incorporate improved technologies in transportation modes, fuels, and engines.

Two strategic objectives for R&D in the transportation system are linked to the global objective of efficient systems use. These objectives are to develop more energy-efficient transportation systems and to improve the management of transportation systems.

## **Planning and Policy**

Energy conservation is only one objective of energy planning. Measures to improve the efficiency of transportation energy include using more efficient transportation modes, promoting economic interfuel substitution in a given mode, reducing vehicle distance traveled per passenger or per tonne-kilometre, and lowering the energy intensity per vehicle-kilometre.

All approaches to the analysis of the supply, consumption, and conservation of alternative transportation fuels should include energy-demand analysis; supply potential and opportunity costs, end-use requirements, and managerial and other skills; market penetration scenarios; and implementation strategies. For a national alternative fuel program in a developing country, it is necessary to analyze global supply and demand. After these are established, a rationale for a program in alternative transportation fuels is neces-

sary. The establishment of such a program is rarely based on economics. It is more often a strategic political decision to lessen the country's dependence on foreign imports and to reduce vulnerability to shortages or high prices. The development of such a program, particularly in the developing world, can be severely constrained by the lack of a clear political decision. To achieve a stronger political will, consensus should be sought among key protagonists (automakers, oil marketers and retailers, refinery owners, alternative fuels producers, traditional fuels producers, farmers, and scientists).

The potential impacts of such a program include net foreign exchange savings, rural employment and urban migration, energy self-reliance, a conflict between using crops for food and export and using crops for fuel, environmental effects, and the need for foreign exchange to finance the program.

If an efficient supply system is a global objective, there are two high-priority strategic objectives for R&D efforts in planning and policy. These objectives are to plan for market penetration of alternative fuels and conservation and to develop policies for optimal market penetration of alternative fuels and conservation. Tactics for the first strategy include the development of market-penetration scenarios for alternative transportation fuels and the financial and economic assessment of these scenarios. Tactics for the second strategy include an examination of the impact of pricing, economic, fiscal and trade policies, capital allocation criteria, and institutional and legislative frameworks.

## Volume 7

# Nonconventional Energy

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*Volume editor: Mohan Munasinghe*

# **Market Potential for Renewable Energy Technologies**

*David Jhirad*

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## **Overview**

This paper examines the economic and financial feasibility of new and renewable sources of energy and discusses some examples of their application in developing countries. Renewable energy can be financially and economically competitive for certain applications. A number of cost goals must be achieved if solar photovoltaic or thermal systems are to make a major contribution to the energy sector. The paper contains a discussion of methods for evaluating projects in the public and private sector and identifies a series of issues that must be addressed if renewable energy is to have a significant impact on development.

## **Analysis**

Three basic facts must be considered in the analysis of options for renewable energy. First, renewable energies are technically capable of supplying modern society with many of its energy requirements. Second, renewable energies have not been exploited internationally, although they are economically competitive with conventional fuels. The main obstacles are institutional. Third, efficient use of systems

based on solar energy will depend on advanced materials and concepts to make this option competitive with conventional options.

## **Renewable Energy Resources in Developing Countries**

Renewable energy includes both direct solar radiation and indirect solar energy (for example, wind, hydroelectric power, ocean energy, and sustainably managed biomass resources). Despite the First World's strong interest in renewable energy, this interest has not been reflected in the energy strategies of developing countries. Renewable energy has a number of advantages. Because it is an indigenous resource that can be exploited with flexible and modular conversion technology, it is economically efficient for certain applications. Furthermore, rapid technological advances are expected to expand the applications for renewable energy in the near future. Among the barriers to the spread of these systems are lack of experience with renewable energies, lack of institutional support and coordination to finance and commercialize the systems, and technical and economic uncertainties, combined with high costs for many renewable energy options.

Energy planning should be demand oriented and based on development needs. As such, a combination of conventional and renewable energy systems and of measures to ensure efficient use of energy is required.

## **Economic Status and Future Market Prospects for Renewable Energies**

A US study sponsored by the Department of Energy and the Trade and Development Program determined that there are market opportunities in less developed countries (LDCs) for technologies related to biomass, photovoltaics, small hydroelectric units, and industrial solar collectors. Examples of applications exist in several developing countries.

Bagasse, wood waste, and agricultural residues from rice and coconut cultivation could play a major role in the production of



electricity and heat in areas where these crop residues are available. A successful large-scale 10.6 MW facility has been built in Louisiana to produce power from rice hulls. It may be possible to effectively transfer this technology to developing countries. In the 1980s, studies were carried out in Ethiopia and the Pacific Islands to produce briquettes from crop residues.

Energy systems that produce electricity and alcohol from sugarcane have also been introduced in LDCs to revitalize the sugar industry. Brazil's program to produce ethanol from sugarcane is regarded as the most ambitious in the developing world, but by the mid-1980s at least seven other LDCs had commercial ethanol plants either in operation or under construction. Ethanol can also be manufactured from other sugar crops, grains, fruits, and materials high in cellulose (for example, wood). Ethanol programs have been introduced in Malawi, the Philippines, and Zimbabwe; however, the feasibility of these programs depends both on the site and on appropriate institutional arrangements and coordination.

The high cost of modules and systems is the major obstacle limiting the use of photovoltaics in LDCs. However, breakthroughs in thin-film technologies may lead to significant reductions in the cost to produce power. Although the cost of photovoltaic technology remains too high for many applications in developing countries, this energy option is the one that holds the most potential. A modest market exists for rural electrification, water pumping, and telecommunications.

Renewable thermal energy obtained with solar flat-plate collectors is expensive and unreliable. Nonetheless, a solar collector made with polymer film and laminate technology is being developed to reduce costs and increase thermal efficiency. Low-cost solar collectors may be highly economical for heating water in the cotton, dyeing, and food-processing industries. Small hydroelectric power units may have important applications in the highland areas of Africa, Asia, and South America, where the lack of electric power and diesel fuel limits economic development.

## **Project Analysis and National Energy Policy**

To achieve their goals in energy costs, governments must perform social cost-benefit analyses of renewable energy projects using appropriate shadow prices. Once a project is proven to be economic, planners can consider the financial feasibility of the project from the point of view of the investor. The financial feasibility of renewable energy systems largely depends on the price of oil and the cost of capital. The standard criteria for cost-benefit analysis are the internal rate of return (IRR), net present value calculations, and gross pay-back period.

Solar industrial process heat (SIPH) systems are an example of the effects of government policies on the financial feasibility of energy systems. A sensitivity analysis of key parameters reveals that given the market price of oil, SIPH is uneconomical unless cost-reducing innovations are implemented. In 1981, with premiums of more than 50% on the world price of imported oil, SIPH investments became economic. Investment tax credits are also a powerful government tool to encourage investment in solar energy. For example, a 25% tax credit on one installation can make the difference between a project with an attractive IRR and one with a very low or even negative IRR.

## **Suggestions for Further Research**

If renewable energy systems are to have a major impact in the developing world, these issues must be resolved:

- LDCs must incorporate strategic planning in their energy sectors.
- A coherent national policy on energy, which includes coordination of institutions, must be developed.
- The benefits of indigenous manufacture compared with imported technology and equipment should be explored (technology transfer should involve joint ventures with companies in industrialized countries to avoid continued dependence).

- Performance standards should be established for various types of renewable energy equipment, and information should be disseminated on technologies that meet standards of reliability and efficiency.
- Governments should provide incentives for renewable energy investments on a clear and consistent basis and provide training for skilled labour.

# **Solar and Wind Energy Technology**

*Bernard McNelis and Peter L. Fraenkel*

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## **Overview**

This paper discusses conversion technologies for solar and wind energy. Applications and costs are outlined. The economics of solar and wind technologies are compared with those of diesel engines. Recommendations focus on the collection of more reliable information to determine what a technology can achieve and where it can be used.

## **Analysis**

Largely because of their high capital costs, solar and wind technologies have not had widespread impact as energy options. However, costs of renewable systems are falling, and markets may soon develop. So far, few systems have proven to be technically or economically feasible. There is a lack of economic and technical data on existing projects. Research and development have been led by technology. Instead, research should be devoted to end uses and an assessment of what current technology is able to achieve. The seasonal and geographic variability of both solar and wind energy must be accurately recorded and duly considered in the design of any related energy system.

## **Conversion Technologies for Solar Energy**

Solar radiation can be converted to heat and mechanical or electrical power. The heat can be used to heat or distill water or to dry crops (conversion is carried out by solar thermal collectors that circulate air or water). Mechanical or electrical power can be used for water pumping, lighting, and refrigeration (this more complex conversion uses solar-thermodynamic or solar-photovoltaic methods).

**Solar Collectors** — Solar collectors are classified according to geometry and vary in efficiency. Common types are flat-plate collectors, evacuated collectors, solar ponds, stationary concentrators, linear-focus collectors, point-focus collectors, and central receivers.

**Thermodynamic Conversion** — Heat can be converted by a solar-thermodynamic power system (heat engine) into mechanical energy to generate electricity. However, there is a basic incompatibility between solar collectors and heat engines: the efficiency of a solar collector decreases as the temperature increases. Thermodynamics dictates that maximum conversion efficiency in the engine requires a large difference in operating temperature. There are three main types of heat engines.

**Photovoltaic Conversion** — Silicon cells require a thin wafer of high-purity silicon processed into a crystalline form. There are several cell types. Until recently, the most common form was monocrystalline silicon, which is cut from a single, long, processed crystal. Current conversion efficiencies are 12–18%. Polycrystalline silicon, composed of many individual grains of silicon, has less stringent requirements for crystal growth and can be cast as a block. This implies more efficient use of the silicon feedstock and less expensive production. Efficiencies of 13% have been achieved in commercial production, and higher efficiencies are planned. The commercial potential of thin-film cells is being evaluated, and the technology continues to evolve. Because the photosensitive layers are very thin, little material is used and costs are reduced. A theoretical efficiency of 15% is possible but has not been achieved.

Modules and arrays of solar cells can be electrically connected in series or in parallel to provide suitable voltages and currents for particular applications. Efficiency decreases as the operating temperature rises.

## **Applications and Costs**

Solar technologies must be evaluated in the context of their end uses. Only technically and economically feasible technologies, or those with the potential to become feasible, should be considered.

Possible applications for solar collectors include

- Water heating, which is the best known and most widespread use of solar technology and may save fuel in urban and industrial applications,
- Water distillation, which can be used for water purification in developing countries, and
- Solar dryers, which can improve traditional methods of drying fish and produce.

There are few solar-thermodynamic power systems in regular operation. However, research suggests that it should be possible to produce technically reliable and economically feasible systems. Most experience with small systems has been with water pumps. A comparison of system configurations indicates that higher temperature solar collectors have lower system costs for a given output. Therefore, the capital costs of mass-produced thermodynamic systems could be competitive with the projected capital costs of photovoltaic systems. In addition, solar-thermodynamic systems will probably be more feasible for large-scale applications.

There are two main types of photovoltaic systems:

- Stand-alone systems, in which the photovoltaic array is the principal or only source of energy, serves both alternating current (AC) and direct current (DC) loads (the factors that determine the size of the photovoltaic array and the amount of battery storage required include location, required availability, duty cycle, and energy demand).

- Grid-connected systems have the load connected to both the photovoltaic power system and an electricity grid (these systems are not yet appropriate for developing countries).

Stand-alone systems are used for both water pumping and medical refrigerators. There are at least 600 photovoltaic pumping systems installed around the world. Few have been monitored. The subsystem must work efficiently over a range of voltage and current levels. The choice of a DC motor is attractive because the array provides a DC power supply. For high-power applications, AC motors with DC-AC invertors can be used.

Pumps can be centrifugal or positive-displacement. Each has different characteristics that suit different applications. Four principal combinations of motor and pump are suitable for different ranges of head and flow. Lifts range from 2 to 20 m and electrical efficiency from 25 to 40%.

Photovoltaic cells can also power small refrigerators, which are technically feasible and economically attractive for vaccine storage in remote areas. Photovoltaic cells are not yet economic for powering domestic refrigerators.

## **Conversion Technologies for Wind Energy**

Most wind systems operate with a wind speed of 2.5–25 m/s, but no system covers the entire range. The two primary mechanisms for producing forces from wind are lift and drag.

The two main families of windmills use either horizontal- or vertical-axis rotors. Horizontal-axis rotors depend mainly on lift and require fewer blades. The power coefficient and the torque coefficient are both used to classify a horizontal-axis rotor. The choice of rotor is based on the load characteristics.

Vertical-axis rotors can be either drag- or lift-based. The Savonius rotor has been adapted to produce shaft power. Panamones are pure drag devices and are less efficient than lift-dependent devices. Cross-flow or Darrieus wind turbines, which depend on lift for their power production, are limited in their commercial availability.

## Applications and Costs

The two main applications of wind turbines are as wind pumps and electricity generators. A pump generally involves a high-solidity rotor (with a low tip speed ratio) that is connected mechanically to a piston pump, whereas a generator is usually driven through a gearbox by a low-solidity rotor. Typically, a wind turbine will run only when the wind exceeds a certain minimum speed, and the output increases progressively with the wind speed.

**Wind Pumps** — The two principal end uses of wind pumps (water supply and irrigation) have very different technical, operational, and economic requirements. Because pumps for water supply are often left unattended, they must be reliable and are generally more costly. Irrigation pumps are for seasonal use. They are generally attended and need not be as reliable or costly. A number of pumps can be used with windmills. Mechanical wind pumps generally operate with a positive displacement pump; however, major mismatch problems can limit system efficiency and must be considered in system design.

Developing countries have only started to manufacture wind pumps, and the industry is not yet fully established. A comparison of wind pumps indicates that the cost per square metre of rotor is relatively independent of machine size. Furthermore, European and US machines are more expensive than Asian or Australian models. Commercial models are based either on obsolete but reliable designs from the 1930s or on immature, relatively untested contemporary designs. A lack of interest in wind technology was evident during the 20–30 years preceding the oil crisis. Because of a lack of scientific research and accurate measuring equipment, the design of wind pumps is empirical, and some machines could be improved significantly by controlled testing.

The global market for wind pumps is difficult to assess, but if it is assumed that there are about 750 000 wind pumps with a lifetime of 20 years now in use, the existing market should be 37 500 pumps per year. If the trend to replace wind pumps with engines halts, a significant market could exist, especially if modern cost-effective designs can be produced.



**Wind Generators** — Wind generators have been installed in increasing numbers in the United States. The average capacity of the wind generators installed in 1983 was 66 kW. Smaller wind generators (either grid-connected or stand-alone) are also available to charge the batteries used in rural lighting, communications, and vaccine refrigeration. Because many First World manufacturers concentrate on larger machines for electricity grids, there is a shortage of generators to charge the small batteries that are used in many less developed country (LDC) applications. Cost analysis reveals that small wind generators would be less expensive if produced in quantity.

## **Economics of Solar and Wind Technology**

The costs of solar, wind, and diesel systems are high in comparison with the market price for conventional electricity. The unit energy costs for renewable energy systems depend on both climate and the energy load on the system. Because it is difficult to compare capital costs for these different units, their cost–power outputs were compared. The comparison revealed that

- In windy regions, wind generators were cheaper than diesel engines for a daily load of 2 kWh or less,
- For very small loads, with good solar conditions or medium wind speeds, capital costs of solar and wind systems were less than that of diesel systems, and
- Medium wind conditions made wind generators cheaper than solar systems even with good solar conditions.

A comparison of unit energy costs for all three systems showed that

- Given a 4.5 m/s average in the worst month, wind was competitive with diesel under all conditions,
- For loads of less than about 5 kWh/day (1 kWh = 3.6 MJ), wind was competitive at 3.5 m/s and photovoltaics at 20 MJ/m<sup>2</sup>, and
- For loads less than 1 kWh/day, photovoltaics were competitive at 15 MJ/m<sup>2</sup> and wind at 3 m/s.

## **Suggestions for Further Research**

Research to improve the conversion technologies for solar and wind energy is important; however, several technologies are at the stage where widespread use in LDCs is not dependent on more technical research. Reliable technical, economic, and social information is required to determine what a technology can achieve and the conditions under which it can be used. Three specific recommendations for future research are the following:

- Field research needs to be carried out to bridge the research gap between the developers and the users.
- Data are urgently required to evaluate the validity of wind pumps.
- A program should be undertaken to determine the potential for using inexpensive stand-alone wind generators in nonelectrified villages in LDCs because wind technology offers considerable potential in agriculture and rural electrification.

# **Geothermal Energy Exploration and Utilization**

*Ingvar Birgir Fridleifsson*

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## **Overview**

This paper discusses geothermal resources and their associated geologic conditions. Exploration methods to locate geothermal resources are examined, and the steps in a typical geothermal project are presented. The paper focuses on preliminary and appraisal studies and presents an overview of practical uses of geothermal energy throughout the world. The costs and uses of geothermal energy are favourable compared with the costs and uses of other energy sources. Given its advantages, geothermal energy is expected to become more widely used.

## **Analysis**

Vast amounts of geothermal energy are generated and stored in the core, mantle, and crust of the Earth. However, this energy source can only be tapped in relatively restricted zones, where heat can be extracted in the form of hot water or steam. The hot water or steam can then be used for electricity generation, heating, drying, or freezing. Geothermal energy, in this paper, refers to the energy stored as water or steam at depths that are accessible by drilling. Locating useable geothermal sources depends on finding a suitable heat source, the presence of a suitable medium for transferring the heat,

and a permeable path along which the medium can travel. Geothermal exploration seeks to find these permeable paths. Geologic resources can be distinguished by their relationship to young igneous intrusions: high-temperature fields are always associated with such intrusions, but low-temperature fields need not be.

The principal geothermal fields used to produce electricity are associated with young igneous intrusions. These intrusions are located on three types of plate boundaries: constructive, destructive, and transform faults. Strong heat anomalies are associated with plate boundaries. Constructive boundaries occur where two plates move apart and a new plate is formed on the ocean floor along the spreading ridge. The most simple geologic type of geothermal system occurs at constructive plate boundaries. These types of boundaries are located in the East African Rift Valley, the Gulf of California, Iceland, and the Red Sea.

Destructive boundaries occur where two plates collide and one is thrust beneath the other along a subduction zone (for example, in Indonesia, Japan, New Zealand, and the Philippines). The geologic activity at the plate is generally very complicated, and there are both positive and negative heat flows.

Transform faults result when two plates slide past each other (for example, California and Hawaii). Geothermal fields are less common at these boundaries because magmatism is not as intense. The best known geothermal system at this type of boundary is Geysers geothermal field in California.

There are also vast quantities of geothermal energy stored in regions of normal thermal gradients where there are no young igneous intrusions. However, only a small fraction of their potential can be exploited economically. Geothermal resources not associated with intrusions can be divided into

- Resources in a low-porosity, conductive environment that can only be extracted by creating artificial permeability (this extraction method is at the experimental stage),
- Resources related to deep circulation of meteoric water along faults and fractures (for example, warm springs),

- Resources in a high-porosity environment at hydrostatic pressure (these are the most important type of geothermal resource not associated with young igneous activity), and
- Resources in a high-porosity environment at pressures greatly in excess of hydrostatic pressure.

## **Geothermal Exploration**

Geothermal exploration deals with a much wider scope of geologic structures than oil exploration and is further hampered by the low unit cost of the final product. Because geothermal fields are such complicated geologic and hydrologic phenomena, their exploration involves the integration of methods derived from geology, geophysics, and geochemistry. Much can be learned from oil exploration methods because geothermal reservoirs are often discovered in the course of investigations for oil and gas. Typical steps in a geothermal exploration project include an appraisal study, project design, preparation of tender documents, project construction, and plant operation.

The preliminary study can be divided into a reconnaissance survey to identify specific prospect areas and to assign priorities for more detailed investigations, prospect investigations to locate exploratory drill sites within a prospect area, and exploratory drilling to prove the existence of a geothermal reservoir. The preliminary study yields a prefeasibility report that is used to decide whether to continue with the appraisal study. The appraisal study can also be divided into appraisal drilling using wells that are of similar construction to the planned production wells, reservoir evaluation using flow tests and interference tests in the wells, and the feasibility study.

The issue of whether geothermal energy constitutes renewable energy remains unresolved. Generally, over time, the pressure in these fields declines; however, the lifetime of a field can vary widely (it is generally assumed to be 30 years in feasibility reports). ReInjection of the field with the geothermal fluid can help to maintain the pressure, but the long-term effects of this mechanism have not been determined. The surface thermal-flux and volume methods are most widely used to estimate geothermal resources on a regional scale.

## Geothermal Utilization

Like solar energy, geothermal energy has been used for centuries, but it was not until the beginning of this century that geothermal water was used to heat houses in Iceland and to generate electricity in Italy. Geothermal energy use is often divided into electricity production and direct applications. In general, production of electric power requires temperatures above 140°C, whereas the ideal temperature for district heating networks is 80°C. Because of the low efficiency of steam turbines, 7–10 MW of thermal energy is required to produce 1 MW of electricity. Therefore, more attention is given to direct applications of geothermal resources.

Electricity production is limited by the pressures at which the turbines can operate. In 1985, 16 countries, including China, Italy, and the United States, were using geothermal power to generate electricity. The annual growth of electricity produced from these resources was 16.5% from 1978 to 1985, and developing countries (for example, Costa Rica, Ethiopia, and Guatemala) were expected to join this group by 1990. Indonesia, Mexico, and the Philippines produce electricity from geothermal energy. The rate of development of geothermal electricity in the short term will probably be greatly determined by the price of oil.

There are many direct applications for geothermal energy using familiar technology. In comparison with geothermal electricity, direct applications are characterized by higher efficiency, shorter development time, and wider availability. Seventy countries are believed to have some low-temperature geothermal resources that could be used for direct applications.

Japan is the world's largest user of this energy source. More than 90% of the energy is used in baths and swimming pools. Iceland is second with 10% of the energy used in industry, 5% in greenhouses, and 85% in heating. In 1985, about 80% of the population of Iceland was served by heating systems that relied on geothermal power. Hungary is the third largest consumer of geothermal energy, and 45% of its energy goes to industrial and agricultural applications and 35% to greenhouses. France is a pioneer in the use of low-temperature

water obtained from aquifers in saline basins with normal heat flow. By using cogeneration (geothermal energy and conventional energy), France's ambitious goal is to heat the equivalent of about 800 000 apartments by 1990. China has also set ambitious goals for the exploitation of this energy source. Geothermal energy has been used on a large scale in the textile industry in Tianjin. Large-scale heating systems are being planned in Tianjin and Beijing, where 200 000 m<sup>2</sup> of houses are already heated by geothermal energy.

An additional potential benefit of geothermal exploration is the use of aquifers for the long-term storage of thermal energy. Large amounts of energy dissipated from conventional oil- or coal-fired power stations could be stored in the aquifers of low-temperature geothermal reservoirs. Other sources of energy that could be stored include waste heat from solar and industrial processes. Aquifers could also be cooled in the winter to provide summer cooling.

### **Comparison of Geothermal Energy with Other Energy Sources**

Geothermal energy costs must be compared with the costs of conventional fuels and of other renewable energy sources. This is a complicated task because of price distortions in the energy sector, unreliable data, and changing interest rates. Nonetheless, private oil companies have capitalized over half of the world's development of electricity from geothermal resources. Geothermal energy would seem to compare favourably with other energy forms. In many countries (for example, Iceland, New Zealand, and the Philippines) geothermal electricity compares well with conventional electricity in terms of reliability, economy, and scale of production plants. In Iceland and France, geothermal energy is competitive in its use for direct applications.

Although geothermal energy may never supply more than 1% of world demand for electricity (it accounted for 0.2% in 1984), it could be a major energy source for certain developing countries (for example, El Salvador, Indonesia, Kenya, Mexico, and Nicaragua). Its potential as a source of heat may be even more substantial.

## **Suggestions for Further Research**

Considerable research is required to adapt common industrial processes that consume large amounts of thermal energy. There are opportunities for geothermal energy in the fields of food processing and distillation. The field of drilling technology also requires more research because drilling consumes a large percentage of the investment in geothermal projects.



# **Photovoltaic Technology: Application in Developing Countries**

*Antonio Luque*

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## **Overview**

This paper concentrates on the most recent photovoltaic technologies and assesses the role that developing countries can play in the development of these technologies. Research has been carried out on three types of photovoltaic technology that are based on semiclassical, thin-film, and concentrating approaches. Each approach is described. Four markets for photovoltaic generators are identified. The paper concludes with a discussion of policies to improve the application of photovoltaic technology in developing countries, recommends a national photovoltaics policy, and discusses the need to understand local market conditions.

## **Analysis**

Because supplies of fossil fuels are limited and the energy produced from these fuels is only inexpensive when it is available from centralized power plants, solar energy is likely to become an increasingly important source of electricity in developing countries. Photovoltaic technologies will probably be more widely used than other means of producing solar electricity because they provide an effective method of producing electricity for scattered users, are reliable, are easy to operate, and can be manufactured in LDCs.

## **Recent Developments in Photovoltaic Technology**

From 1974 to 1984, three types of photovoltaic technology occupied much of the research effort (semiclassical, thin-film, and concentrating approaches). When analyzing these approaches, it is important to recognize that the cost of photovoltaic generators varies widely and depends on the size and nature of the market. It is also important to note that the maximum efficiency that can be achieved in practice is 25%.

Semiclassical approaches characterized the industrial structure of the mid-1980s, when manufacturers purified silicon for use in photovoltaic sheets, cells, and panels in separate plants. A number of attempts were made to reduce the cost of this method. Several industrialized countries attempted to produce a lower purity polysilicon, but the cells had disappointingly low efficiencies. Other techniques have included the use of multiwire saws to cut ingots into wafers more efficiently and continuous growth of a single crystal into the shape of a sheet. The methods with the most potential are the multicrystalline wafer, multiwire slicing, and continuous sheet growth.

The most promising improvement in cell manufacturing in the early 1980s was the elimination of expensive vacuum steps from the process of metal deposition. Major factors in the cost of cells include wafer cost, manufacturing yield, and efficiency.

Two types of thin-film cells, the compound semiconductor and the amorphous or a-silicon cell, were developed in the early 1980s. Thin-film cells reduce the amount of active photovoltaic material because they use a substance that can absorb light in a few micrometres. This technology is characterized by purification difficulties because of the high surface-volume ratio and by instability. Consequently, efficiency has only reached 10% in the laboratory and 5.6% in the field (10% is considered average), and performance declines quickly over time. Despite these difficulties, thin-film cells are a popular research topic in small laboratories in the developing world because limited equipment and materials are required for the devel-

opment of cells. However, because of their instability, easily manufactured cells often become useless in a short time.

A-silicon is considered the most promising thin-film technology. It has enjoyed small-scale use in consumer goods (for example, watches and calculators). The efficiency of thin-film cells must be increased before they can become competitive with crystalline cells. This research is inappropriate for developing countries because the outcome is too uncertain.

The concentrating approach, by concentrating light on each cell, decreases the area of solar cells required to yield a given amount of energy. This cost-saving advantage is counterbalanced by the need for a tracker to keep the cell in focus and by the system's inability to collect diffuse radiation. Consequently, concentrators are only feasible in dry areas with unimpeded direct sunlight. Research into static concentration, which does not require a tracker, would eliminate one disadvantage.

Companies in the United States have financed the installation of concentrating generators because government subsidies make them profitable. There are advantages to manufacturing concentrators in developing countries. The mechanical structure can be produced more easily in countries with an intermediate level of industrialization, optical elements can be made using simple technologies that are more easily transferred than the more complicated methods of cell manufacturing, assembly can be adapted to economies with low labour costs, and concentration makes it possible to adapt specific solutions to local skills. The product can also be as inexpensive on the open market as devices based on more complex technologies, and the risk involved with the technology is low.

## **Applications of Photovoltaic Electricity**

There is a need for governments to support basic research and to subsidize photovoltaic electricity to encourage rural electrification and support national manufacturers. In addition to type of technology and volume of production, the size and nature of the market are the key factors that determine whether a particular technology is economically feasible.

The four basic markets for photovoltaic generators are remote, rural, and residential users and power stations. For remote users, reliability is essential and can be achieved economically using existing flat-panel technology.

The rural market is mainly concerned with the electrification of rural areas. In Spain, for example, this can be achieved more economically using photovoltaics than by using an electrical network. Photovoltaics are cost competitive with diesel generators, and many consumers prefer photovoltaics because they are quieter and more reliable. Although there is a need for these systems, the poverty and isolation of potential users make them difficult to market.

The residential market comprises conventional houses that have generators connected to the electrical network. In 1984, photovoltaic modules were not economically feasible for this application. In addition to capital cost, the market potential depends on the lifetime of the panel and future interest and inflation rates.

Central photovoltaic power stations that used current technology would only be feasible if the price of oil increased substantially. Otherwise, new, more efficient technologies are required to make them competitive with conventional power stations.

Growth in the markets for photovoltaics will probably lead to price reductions in the technology. Before making large investments, LDCs should be aware that photovoltaic devices will be further developed and become more competitive in price.

## **Suggestions for Further Research**

Photovoltaics can be competitive with conventional energy sources in a number of applications. To exploit this energy source, developing countries should undertake the following:

- Assess the potential markets for photovoltaic systems because a significant portion of the cost of small systems is marketing.
- Distinguish between centralized and individual systems, each of which is characterized by unique problems.

- Examine the social benefits of these systems to encourage public subsidies.
- Set up factories to encapsulate or manufacture photovoltaic cells.
- Refrain from establishing large-scale plants because of the risk involved.
- Conduct further research into promising areas (for example, concentrating devices) and monitor the field performance of existing technologies.
- Strengthen regional ties to counteract the master-client relationship prevalent between the North and South.

# **Use of Wind to Generate Electricity in Developing Countries**

*Marshal F. Merriam*

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## **Overview**

This paper discusses the use of wind for electricity generation in the developing world. Technical topics include the four steps necessary for the assessment of the wind resource and its conversion to electricity. The output and costs of the wind industry are described (based on experiences in California). The generation of electricity from the wind is discussed with particular concern for the developing world. Special problems in developing countries include financial, technological, managerial, and physical difficulties. The paper concludes with a discussion of problem areas, R&D priorities, and policy recommendations for LDCs.

## **Analysis**

Because wind speeds fluctuate widely and depend on time and location, equipment should be sited with great care. Potential sites are difficult to identify because the resource is invisible and inconsistent. The four steps needed to assess the wind resource at a given site are

- Preliminary reconnaissance, which includes a review of existing records for localities with mean wind speeds of at

least 5.5 m/s, a review of maps of local topography and weather patterns, and consultation of “local lore,”

- Field reconnaissance, in which a small crew with a vehicle and portable anemometers measures the “run of wind,” looks for wind-modified vegetation, talks to locals, and makes short-run measurements of average wind speed in promising regions,
- Modeling, in which the most promising localities are modeled, either numerically or physically, and
- Site verification, an expensive but necessary step, in which wind speed is recorded for an extended period (months or years) before the commitment is made to install wind generators.

In addition, other factors (for example, proximity to the local power grid) should be considered. Although there is a strong demand for assessments of wind power, data are often sparse, particularly for developing countries, and this makes the first step critical and often extends it.

## **Technological Fundamentals and Limits**

There are several technological fundamentals and limits that govern the conversion of wind energy:

- Wind power is highly variable in both space and time because power available from the wind is a function of air density and wind velocity cubed.
- A good wind installation would have a power coefficient of about 0.3, which means that, on average, the installation would extract 30% of the energy in the wind it intercepts each year.
- Rated wind speed (RWS) is the wind speed the generator needs to reach its rated electrical output (the usual practice is to choose a machine with an RWS 1.5–2 times the average wind speed at the site).
- Plant capacity factors (ratio of average to capacity output) that are economic are generally between 0.25 and 0.35.

- Availability is the fraction of time that the wind generator is fit for service (because maintenance, repair, and replacement of parts must be expected, no generator can be 100% available).
- Solidity refers to the amount of blade material necessary to intercept a certain area of wind.
- Most machines in use today have a horizontal axis (however, vertical-axis designs promise better cost effectiveness and fewer mechanical-drive problems, but they are less reliable).
- The design of generator rotors must focus on two major requirements — the desire to extract as much energy as possible from the wind and the need to control the revolutions per minute and to stop the machine reliably in high winds.

## **Output and Costs**

There are no statistics for the global industry; however, a study of California's experiences shows the outputs and costs of the wind industry. In California, by the end of 1983, there was 239 MW of wind-generated electricity connected to the grid, and projects to generate another 1 202 MW were contracted to be built. None of the California projects would have been feasible without large tax incentives. The most cost-effective wind generators produce in the range of 0.1–0.5 MW. However, emphasis continues to be placed on the development of larger machines, likely because of the influence of the large aerospace firms on the US government.

There seems to be little prospect of commercial grid-connected equipment that could compete with conventional generators in electricity production. In developing countries, the potential for smaller stand-alone wind generators is much greater than in developed countries. If there is a good wind, a small stand-alone wind generator may be appropriate even if the location is not remote. As a matter of public policy, these generators should be emphasized more than grid-connected applications in the developing world. Unfortunately, although the social importance of smaller, stand-alone units is greater, their commercial attractiveness is less.



## **Special Problems in Developing Countries**

Problems encountered in the use of wind energy in industrialized countries may be exacerbated in the developing world. In order of importance, these problems are financial, technological, managerial, and physical.

The financial difficulties stem from the long payback period for grid-connected generation equipment and from severe competition for scarce capital. Rates of return for many projects in LDCs can be much higher (typically 15–30% annually) than for projects associated with grid-connected generation equipment. Therefore, investors may be risk-averse to investment in new wind technology. The use of foreign exchange for the purchase of stand-alone systems can also be a special problem for LDCs.

Technological problems are caused because there is a lack of the support services and facilities that are readily available in the North. Limited availability of trained personnel to erect, repair, and operate the equipment and a lack of imported spare parts are also important problems.

Most LDCs are weak in managerial resources; therefore, employees are used inefficiently. Managerial problems penalize attempts to harness the wind economically.

The physical problems stem from the lower latitudes and warmer climates of most developing countries. Wind speeds tend to be lower and the air is less dense. As a result, less power can be derived from wind energy.

## **Suggestions for Further Research**

The main problems in the generation of electricity from the wind are unreliable equipment, high costs and short life of the equipment, inadequate profits and high risks for manufacturers, and the inability of government demonstration programs to transfer the technology and experience to the private sector or to government-owned corporations.

R&D priorities in developing countries include

- The contracting of local engineering laboratories to develop improved wind generators,
- The local manufacture of inexpensive electronic controls to improve the operation of wind-powered machines and to help develop national expertise,
- The development of a package that consists of a rugged, reliable wind generator operating in parallel with a diesel- or gasoline-driven generator,
- The development of packaged stand-alone systems with battery storage and small generators that could be used for specific purposes (for example, power for runway lights at unattended airstrips, or power systems for lighting, heating, and alarms at park headquarters or small museums in unelectrified areas), and
- The development of a standard wind-farm package for connection to local grids at suitable sites.

Policy recommendations include the following:

- Large and highly visible demonstration projects should be avoided.
- Wind-farms should not be developed for fuel saving in grids unless the fuel to be saved is oil.
- The first projects should be directed toward finding good wind sites.
- The needs and characteristics of the country should be considered in the wind program.
- The need to conserve foreign exchange and national pride may dictate a program of solely indigenous content (local design and construction of wind generators is possible, but only at a cost).
- Government laboratories and universities can play a useful supporting role, but the major portion of any successful wind program must be undertaken by the private sector.
- The idea that the purpose of electricity generation from the wind is job creation should be resisted.



## Volume 8

# Bioenergy

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*Volume editor: Frederico Owino*

# **Research and Development in Alternative Energy Sources**

*J. Lamptey, M. Moo-Young, and H.F. Sullivan*

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## **Overview**

This paper discusses processes for biomass bioconversion and thermochemical conversion. The production of ethanol from lignocellulosics is described in some detail, whereas butanol–acetone and hydrogen production are reviewed briefly. Thermochemical processes to convert lignocellulosics to energy (for example, methanol from synthetic wood gas) are described. Other renewable energy sources (solar, ocean, and wind energy) are discussed briefly.

## **Analysis**

### **Bioconversion Processes**

**Production of Ethanol** — Ethanol has a number of commercial applications as an energy source and as an industrial solvent and chemical. Chemical synthesis and fermentation are the two major techniques used to produce ethanol. Chemical synthesis is the catalytic hydrolysis of ethylene derived from petroleum. For fermentation, which can be carried out through different conversion processes, the four categories of feedstocks are sugar-containing materials (which are the most expensive to obtain), starch (including corn, potatoes, and cassava), lignocellulose (which is the major

renewable carbohydrate source in the world), and urban and industrial wastes. There are problems associated with the collection and conversion of each feedstock to produce a useable substrate.

The structural features of cellulosic biomass make pretreatment necessary. This process, which removes lignin and increases the surface area available to enzymes, promotes hydrolysis and enhances the rate and extent of cellulose saccharification. Pretreatment techniques are classified as physical, chemical, biological, or combined. One physical technique is milling, which reduces crystallinity and the degree of polymerization and increases bulk density. High power requirements make this technique costly. Chemical pretreatment involves the use of strong acids, bases, or agents that swell or dissolve the cellulose. These expensive chemicals are corrosive and toxic, which makes this technique commercially unattractive. Steam explosion, in which cellulose materials are saturated with water under high pressure and temperature, is another physical technique. When pressure is released, the wood fibres separate and the acetic acid that is released catalyzes the hydrolysis of the hemicellulose.

The three principle conversion processes for lignocellulose are acid hydrolysis, enzymatic hydrolysis, and direct microbial conversion. Acid hydrolysis, which is suitable for any cellulose feedstock (but is most often used with wood), can be carried out with dilute or concentrated acids. Because the use of concentrated acids is expensive, most development work involves dilute acids. An increase in acid concentration or reaction temperature increases the production of glucose.

Lignin, a by-product of acid hydrolysis, is likely only useful as fuel. Although acid hydrolysis has many advantages (for example, the ease of use of wood as a feedstock, the short reaction time, and the low cost of the acid catalyst), its limitations include lower potential yield and sugar concentration, the production of degradation products that are toxic to fermentation yeast, and severe operating conditions that produce corrosion.

Unlike acid hydrolysis of cellulosic materials, enzymatic hydrolysis is not yet used commercially. Because the enzymes are reaction specific, this process could potentially produce higher

yields of sugars under mild operating conditions that do not require corrosion-resistant equipment. The major disadvantage is the requirement for an aseptic environment for enzyme production because hydrolysis is susceptible to microbial contamination.

Microbial conversion is also not used commercially, but it has theoretically the highest yields of all techniques. This process seeks to convert cellulose and produce alcohol in a single step using one or two microbial organisms. The conversion is not easily applied because no efficient cellulosic microbe that produces ethanol has been found. Microbes have a low tolerance for ethanol and tend to produce unwanted by-products.

Fermentation systems for ethanol production require substantial cost reductions. To minimize costs, a balance must be struck between three goals for ethanol fermentation (high substrate utilization, high ethanol productivity, and high ethanol concentration). Research is currently under way to increase the rate of fermentation and to decrease costs. Rapid fermentation can be achieved by maintaining a high yeast population and removing rate-inhibitory ethanol from the fermenter as quickly as it is formed. Researchers have used both adsorption and entrapment techniques in laboratory experiments to immobilize yeast and to increase the rate of fermentation. Industrial applications have not yet been developed. Although there seems to be a promising future for ethanol production, the cost of the glucose substrate remains the main bottleneck for fermentation.

**Production of Butanol–Acetone and Hydrogen** — Bio-mass feedstocks can also be used to produce both butanol–acetone mixtures and hydrogen. Fermentation of products containing starch and sugar can produce butanol–acetone mixtures. However, research in improved production technology is required to make the process commercially attractive.

Excluding gasification, hydrogen can be produced from biomass feedstocks by

- Photochemical methods (including a technique to simulate plant photosynthesis *in vitro* and a technique that uses water

solutions of biomass components in the presence of catalysts),

- Biological methods (the use of anaerobic bacteria in dark reactions to ferment the biomass),
- Photobiological methods (the use of photosynthetic algae or bacteria under anaerobic conditions in the presence of light), and
- Biomass–water electrolysis (which involves anode depolarization with a water-soluble, oxidizable material such as glucose).

These processes have not been demonstrated on a large scale, and they may be made obsolete by the direct photocatalytic decomposition of water to hydrogen and oxygen.

## **Thermochemical Processes**

Biomass feedstocks offer a number of advantages for thermochemical conversion processes (for example, high volatility and char reactivity). Drawbacks to this process include the decentralized nature of the resource and the high moisture content of the fuel. Pretreatment processes include cleaning, drying, and size reduction. Drying is crucial.

Thermochemical conversion processes include

- Direct combustion (traditional biomass includes wood and bagasse, but recent projects involve municipal solid waste, hog fuel, and pelleted wood fuels),
- Gasification to produce low- or intermediate-energy fuel gas or synthesis gas (gasification is considered a commercial or near-commercial technology and can, under certain conditions, be used as a substitute for fossil fuels),
- Direct liquefaction to produce heavy oils or, with upgrading, lighter boiling liquid products (liquefaction remains one of the least commercially attractive conversion processes because of its high capital and energy costs), and
- Pyrolysis to produce a mixture of pyrolysis oils, fuel gases, and char (rapid pyrolysis using rapid heating rates has



emerged as a promising alternative for producing liquid fuels).

**Production of Methanol** — Although natural gas is the preferred carbon source to make synthesis gas for the production of methanol, it is possible to generate the synthesis gas from biomass. The two broad categories of wood conversion technologies for methanol production are oxygen gasifiers and pyrolytic gasifiers. The gasification of wood yields hydrogen, carbon monoxide, carbon dioxide, and other gases. The raw gas is purified and processed to extract a 2 : 1 ratio of hydrogen – carbon monoxide. The synthesis gas is then compressed and passed through a methanol synthesis reactor. The major disadvantages of this process are the size of plant and the amount of raw material required.

### **Other Energy Sources**

Other sources of renewable energy are solar energy, ocean energy, and wind energy. The three categories of direct solar energy are solar heating and cooling, solar thermal, and photovoltaics. The most promising application of solar energy may be in heating domestic water and buildings. Few industrial applications are currently demonstrated or operational. Research in solar photovoltaics is focusing on cheaper fabrication methods and materials for photovoltaic cells. Eventually, photovoltaics may be used for central power generation in conjunction with a conventional backup system. The diffusion of solar technology depends on cost, the solution of technical problems, and the rate of adoption of the technology.

Research is currently being undertaken in ocean energy to exploit the incident solar energy absorbed by surface waters and the energy available in ocean waves. Wind energy is another research area. In locations with strong winds and high fuel costs, wind turbines are already economic.

# **Biomass Energy Development**

*Annalee Ng'eny-Mengech*

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## **Overview**

This paper reviews a number of different sources and processes for producing biomass energy. The important link between biomass energy and agriculture is emphasized. There is justification for a less developed country (LDC) to use agriculture to produce fuel if this stimulates the agricultural economy. A detailed description of ethanol production from carbohydrates and cellulose is provided, and anaerobic digestion is explained. Current research efforts to find plants suitable for the extraction of vegetable oil and hydrocarbon fuels from biomass are examined. Environmental, sociocultural, and economic considerations associated with different bioenergy sources and production methods are highlighted.

## **Analysis**

Effective use of biomass for energy in LDCs is pressing because of the increasing demand for energy to fuel economic growth and the decreasing supplies of fossil fuels. There is an inextricable link between biomass energy and agriculture because the agricultural sector is a major source of supply. In LDCs, biomass can be used for energy production if it directly stimulates the agricultural economy. This stimulation may help to reduce migration to urban areas and may provide the energy needed to improve agricultural productivity. Whether current productivity is increased or new lands are brought

under cultivation, major investments will be required. In Brazil, government incentives have induced the expansion of sugarcane agriculture at the expense of food crops. Therefore, food crops may be dislocated to marginal lands, and this may cause an increase in food prices. A solution to the food–fuel issue can be the cultivation of energy crops that do not compete with food sources. These crops include

- Multipurpose crops with both food and fuel potential (for example, maize, soybean, cotton, pines, cane, sorghum, and cassava),
- Cash crops grown between the harvesting and sowing of the main crop (for example, fodder, kale, barley, and short-rotation grasses),
- Marshland crops (for example, cattails, reeds, water hyacinths, and marine crops such as giant kelp and other seaweeds), and
- Marginal-land crops (for example, bracken).

### **Environmental, Technical, and Economic Impacts of Biomass Production**

The most negative environmental impacts of biomass production are erosion and water pollution. The inherent problems of monocultures may also appear if only energy crops are raised. Deforestation to establish agricultural land results in soil erosion, the loss of habitats, and the disruption of watersheds.

However, alternative biomass technology exists that could have positive impacts. The expansion of biogas units has raised health standards in China. These units also function as a system of waste disposal for pig manure in the Philippines. Domestic wastes and sewage provide substrates for anaerobic digestion and can be used for ethanol fermentation. Water hyacinths can also be used for water purification. Finally, ethanol production and biomethanation dispose of wastes that would otherwise be dumped or burned.

Energy supplies are beneficial only to the extent that their use is practical and economical. When developing alternative technologies for biomass conversion, one needs to consider several conditions.

Equipment should be appropriate for local conditions and users. A supportive institutional infrastructure that includes training and maintenance facilities should be established. Local participation should be included to assist technology transfer.

The evaluation of options for fuel supply involves a range of economic, sociocultural, and political considerations. Traditional philosophies of Western economic development continue to be applied to the evaluation of biomass technologies despite the fact that cost-benefit studies should include environmental, social, and political concerns. Biomass projects should be evaluated on an individual basis (in the same way as coal and gas projects).

The development of alternative energy supplies is not a goal in itself, but a means of achieving a better standard of living. Therefore, a project must be investigated for its social impact. Biomass systems may exacerbate the social imbalances of LDCs when related subsidies favour the rich. Large-scale projects may eliminate small farms (the case in Brazil). In addition, changes in energy production may limit the availability of traditional fuels that are available for free collection and use by the poorest segment of the population.

Other factors to consider in the establishment of a successful bioenergy program are the supply of reliable labour, the integration of women in the program, the impact of cultural customs and taboos, and patterns of settlement. Ultimately, the decision to implement a biomass project is a political one that requires the support of the government.

## **Production of Ethanol from Carbohydrates**

Because the market price of feedstock is the most important factor in the economics of ethanol production, the discovery of new crop varieties and the development of hybrids are integral to energy research. For example, a high-yield variety of sweet sorghum is being examined as an ethanol feedstock. Improvements in cultivation techniques and the discovery of nonconventional crops that grow well on marginal lands will help to reduce the cost of feedstocks. Wastes can also be used as feedstocks, but their use is limited because of storage problems and the lack of year-round availability.

Pretreatment is usually required for ethanol production whether the feedstock contains sugar or starch. Traditionally, mills are used to pretreat the sugar feedstocks to release the juices that contain the sugar. Developments that eliminate the need for roller mills make small-scale operations more competitive (for example, the injection of low-pressure steam into coarsely chopped feedstock, and solid-phase fermentation).

The pretreatment of feedstocks that contain starch requires the reduction of starch to glucose partly by milling and grinding and partly by chemical means. In chemical pretreatment, enzymes are used to liquefy the starch and to carry out the saccharification. Research is being undertaken to discover faster acting thermophilic amylases for liquefaction. A simultaneous saccharification and fermentation process, which lowers costs, has been developed by a Japanese company.

After pretreatment, the mash is diluted to a suitable sugar concentration for fermentation. Although yeasts possess many of the characteristics of a good fermenting organism, bacteria may be superior because they have shorter doubling times and are easier to handle and manipulate. Research is directed toward the discovery of new microorganisms that can withstand high temperatures and high alcohol concentrations and can ferment at high rates.

Ethanol is recovered from the aqueous solution by distillation, which accounts for over half of the total energy consumed by the distillery. Improvements in the energy efficiency of distillation could reduce costs. Alternative methods of alcohol separation (for example, membrane isolation, solvent extraction, and reverse osmosis) have not been tested on an industrial scale. If essentially anhydrous ethanol is required, the 4% water remaining from simple distillation can be removed by distillation with a water-immiscible solvent.

Ethanol production yields a number of marketable by-products. Their value is important in assessments of the cost of production. Bagasse from sugarcane and sorghum allows their fermentation to be nearly self-sufficient in energy supply. Excess bagasse can be used for crop drying, electricity generation, biogas or ethanol production, or conversion to paper or animal feed. By-products of the fermenta-

tion stage include gaseous carbon dioxide that is used in the beverage industry and excess yeast that can be recycled or sold. Stillage — the residue remaining after distillation — has important uses in animal feedstocks, fertilizers, and biomethanation. The proper disposal of stillage represents the biggest environmental problem associated with ethanol production. Other environmental problems include personal hazards and air pollution from the use of alcohol fuels. The data do not clearly show whether gasoline or ethanol produces higher emissions of polluting chemicals.

The establishment of an industry to produce ethanol is often justified on the premise of national self-sufficiency and the creation of new jobs. Smaller units may be more relevant to poorer countries because they make better use of unskilled labour. Nonetheless, even small units require large investments by developing world standards, and it is unlikely that they can be built by individual farmers. Community distilleries may require investment and market guarantees to function. LDCs have experienced difficulties in the establishment of large, successful facilities.

Ethanol production is never economical in purely monetary terms because of the high cost of the feedstock, which can be used as a food source or an export. Therefore, government subsidization is necessary if ethanol is to compete with gasoline.

## **Ethanol Production from Cellulose**

Pretreatment is necessary to make the cellulose component more suitable for enzyme hydrolysis. Mechanical reduction of size is usually a preliminary pretreatment step, and it is generally followed by either acid pretreatment or enzymatic delignification. Delignification is preferred because it does not decompose the sugars. Alternative pretreatment methods are solvent extraction and steam explosion.

After pretreatment, hydrolysis is undertaken with acids, alkalis, or enzymes. Because glucose inhibits the activity of most cellulase enzymes, it should be removed from the reaction medium. However, some microorganisms or enzyme systems can simultaneously hydro-

lyze cellulose and ferment glucose to ethanol, which eliminates the difficulties associated with glucose.

The by-products of cellulose-derived ethanol also influence the cost of production. If hemicellulose sugars are to be exploited, microorganisms must be found to convert them to liquid fuels. Hemicellulose can also be used as the source of other industrial chemicals (for example, furfural). Lignin, the other major by-product, can be used as a source of phenols and benzene and as a source of fuel. Despite the value of these by-products, ethanol derived from cellulose is not competitive with alcohol derived from sugar or starch.

## **Anaerobic Digestion**

Biogas derived from anaerobic digestion is more efficient as a cooking fuel than kerosene or solid biomass, and it can be substituted for kerosene as a heat and light source. Anaerobic digestion also produces solid sludge, which can be used as fertilizer or as animal and fish feed. All types of biomass can be converted, at least partially, by anaerobic digestion. Recent research on feedstocks has included crop wastes, agro-industry by-products and wastes, human waste, domestic waste and refuse, industrial effluents, aquatic vegetation, and terrestrial crops. Digestion kinetics can be improved by improving and isolating new anaerobic microorganisms, increasing microorganism concentration by recycling digester effluent or enriching the level of microorganisms with external cultures, and increasing the feedstock concentration.

There are many types of digesters (vertical, cylindrical, fixed-dome, plastic, and simple ones made from oil drums). The choice of digester depends on budget, local conditions, and know-how. Temperature control is an important aspect of digester operation, and subterranean digesters are better insulated against climatic variations. In the developing world, expensive individual digesters will not benefit the poor unless there are government subsidies. Community digesters can be economically feasible but have seldom been successful.

## **Vegetable Oil and Hydrocarbon Fuels from Biomass**

Plants that photosynthetically reduce carbon to hydrocarbons are potential sources of liquid fuels for petroleum replacement. *Euphorbia lathyris*, which is widespread on marginal lands throughout the world, was targeted as a likely candidate for exploitation, and many studies on its feasibility as a hydrocarbon producer have been undertaken. The results have been disappointing, but other plants may be more suitable. Systematic surveys of indigenous species have been carried out worldwide. The concept of the multipurpose crop that could supply both fuel and raw materials spawned the analysis of over 1 000 wild North American plants to determine their whole-plant oil, hydrocarbon, phenolic, and bagasse content.

Vegetable oils may be economically preferable to other biomass-derived fuels because the oils can be easily extracted from the plant parts. Seeds must be cleaned, dried, and dehusked before they are placed in the expeller. Vegetable oils can be used as an additive to diesel fuel, admixed with gasoline, or cracked into high-grade gasoline. Because of their lower volatility, they are being developed for use in compression-ignition engines. For this purpose, their viscosity must be reduced either by blending with fatty acids or by esterification to produce methyl or ethyl esters, which are more volatile than the parent oils. Indigenous plants have also been subjected to worldwide screening for their seed-oil content.



# **Biomethanation**

*Norman L. Brown and Prakasam B.S. Tata*

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## **Overview**

This paper covers biomethanation at the household, community, and industrial levels. Biogas technology in the developing world is described from a historical perspective, and the properties, uses, substrates, and production technologies for biogas are discussed. The microbiology of biomethanation is explained. The biomethanation process and the factors that influence performance are described. The paper also presents lessons learned from experiences with biogas installations and makes recommendations for further research.

## **Analysis**

In China and India, biogas technology has been used for more than 50 years. Interest in biogas in China was revived in the 1970s, and biogas has been successfully used to provide cooking fuel and to conserve fertilizer and improve public health. This pioneering work stimulated interest in other countries (for example, Korea, the Philippines, and Taiwan). Although most of the activity has taken place in Asia, a number of African and Latin American countries are currently engaging in biomethanation projects.

## **Biogas**

Biogas is made up of methane and carbon dioxide in variable ratios (generally 50–70% methane and 30–50% carbon dioxide). The heating value of biogas is directly proportional to its methane content. Biogas can be used as a cooking fuel and in any gas-burning appliance that requires low-pressure gas (for example, lamps and refrigerators). If the removal of carbon dioxide is feasible and pressure containers are available, the remaining methane can be used as a transportation fuel. The residue from biomethanation has been used traditionally as a soil conditioner or fertilizer because the process produces chemical forms of minerals that are more soluble than the original forms. Because of evaporation problems, residue to be used as fertilizer should either be stored in a closed container or used immediately. Residue is also used as a feed supplement.

Any biomass can be considered as a potential source for biomethanation, but materials such as lignin, bark, and feathers, which are not easily degraded by microorganisms, are not desirable feedstocks unless they are pretreated. The most common feedstocks are crop residues, manure, and human excrement, although other feedstocks (for example, industrial wastes and marine and aquatic biomass) are also used. Generally, the feedstocks have competing uses as food, fuel, fibre, fodder, or fertilizer. These uses must be evaluated before investing in biomethanation. Information on the potential availability of crop residues, manure, and industrial wastes in developing countries is sparse, and this makes evaluation more difficult.

## **Production Technology**

Biomethanation is accomplished by four interdependent groups of bacteria under anaerobic conditions. A group of hydrolytic and fermentative bacteria produces simpler organic compounds (for example, sugars, alcohols, fatty acids, hydrogen, and carbon dioxide). Acetogenic bacteria act on these products to produce methane and carbon dioxide. If the organic load received by the digester is excessive, too much hydrogen is formed and the acetogenic bacteria may

be “washed out” before the methane bacteria have had a chance to use the excess hydrogen. This situation results in a “stuck reactor.” The rate of digestion in biomethanation is related to the nature of the substrate, temperature, loading rate, and acidity.

The two broad categories of biomethanation digesters are

- Suspended-growth reactors, in which biological solids are suspended in the contents of the digester (these reactors can be batch or continuous), and
- Attached-growth reactors, in which the biological solids attach themselves to surfaces such as rock, plastic, or ceramic media (this technology is quite recent and not significantly disseminated in developing countries).

Systems to collect gas range from a simple plastic delivery tube for a family digester to the complex systems of large installations, which may include gas scrubbers and bottling equipment. In developing countries, small-scale systems usually consist of a gas holder, condensate trap, and flame arrester. Fixed-dome digesters also include a manometer and safety valve. Condensate traps remove the moisture carried by the gas stream, and they should be drained when they become full. Flame arresters prevent the flame of an appliance from travelling back through the pipe to the gas holder and causing an explosion. Manometers prevent damage caused by pressure buildup in fixed-dome digesters. Piping should be made of plastic or galvanized iron. In LDCs, biogas is not generally purified to enrich its methane content, but various purification methods (for example, scrubbing and physical and chemical absorption) are available to enhance the quality of the biogas. The bottling of biogas for use as a transportation fuel is not economically feasible in the developing world.

### **Collection, Storage, and Pretreatment of Substrates —**

The success of biomethanation depends on a steady supply of appropriate substrates. Collection and storage practices vary with location and depend on economic and sociocultural differences and on the nature of the substrate (solid, semisolid, or liquid). Dung is usually collected manually and transported to a storage pit near the digester.

Dry materials (for example, leaves and crop residues) can be transported to the digester either manually or by animal carts. Wet materials (for example, green leaves and aquatic weeds) can be shredded, dried, and stored. Prolonged storage of putrescible organic matter results in a loss of methane and valuable nutrients.

Pretreatment of substrates that are not easily biodegradable can be done using physical, chemical, and biological methods. Size reduction, steam explosion, and freeze explosion are all suitable pretreatment techniques for cellulosic materials. Heat treatment of biomass increases its digestibility and results in a higher methane content of the final gas. This process can use energy generated from the digester itself. Chemical pretreatment includes acid hydrolysis, alkaline hydrolysis, and the application of sulfur dioxide. Biological methods include fungi pretreatment to degrade lignin and enzymatic treatment of cellulose to promote saccharification.

**Integrated Biomethanation Systems** — Community-size integrated biomethanation systems have advantages over family-size units:

- Gas production is optimized by incorporating into the digester a good mixing and heating system that can be properly controlled by trained personnel.
- Resource recovery can be enhanced by the use of effluents as feed supplements.
- Pathogens can be controlled and the environment can be protected by the proper operation and maintenance of the system.

Biomethanation systems also have social and economic benefits:

- Diseases are reduced because of the use of clean fuel.
- Deforestation pressure is reduced.
- Electricity is made available to rural areas to improve living standards.
- Additional protein is made available because of the use of algae as a feed or feed supplement.
- Employment opportunities are produced.

**Factors Influencing Performance** — The rate and extent of biomethanation are affected by the nature of the substrate, the bacterial environment, and the design of the biomethanation system. A favourable bacterial environment depends primarily on the need for anaerobic conditions and acidity within a range of pH 6.7–7.6, temperature between 50° and 60°C, proper nutrients, and adequate mixing of the slurry.

### **Lessons from Experience**

It is difficult to learn from the experience of others in biomethanation because experience has largely been at a practical field level, where technological issues cannot be separated from social and economic influences. Rising concern for environmental, political, and social impact also makes traditional economic analysis, by which the technology has been evaluated in the past, inappropriate or at the least open to question. Benefit from the experience of others continues to be hampered by

- The lack of consistent technical, economic, and social criteria by which to monitor and evaluate installations, and
- The lack of consistent cost–benefit methods by which to evaluate the full social costs and benefits.

### **Suggestions for Further Research**

Several areas that warrant further research are

- Efforts to reduce the cost of digesters,
- Investigations of the role of women in the dissemination of biogas technology,
- Controlled studies to determine whether there will be a net benefit if a portion of the biogas is used for heating and mixing,
- Experimentation with less common feedstocks,
- Testing of procedures for uniform reporting of basic data,
- Application of recently developed digester designs in LDCs,
- Comparison of the fertilizer value of slurries obtained from various feedstocks,

- The development of inexpensive and efficient biogas appliances,
- The impact of these systems on public health, and
- Evaluations of the socioeconomic factors that influence the success of various projects.

# **Biomass Energy Technology in Japan**

*Fumitake Tokuyama*

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## **Overview**

The Research Association for Petroleum Alternatives Development (RAPAD) has concentrated its efforts on ethanol derived from cellulose. This paper reviews the research accomplishments of RAPAD, describes efforts elsewhere in methane fermentation and microalgae technology, and discusses the utilization of alternative energy systems in Japan. Conversion technologies and research trends are also reviewed.

## **Analysis**

### **Ethanol Production**

RAPAD has directed its research toward the production of ethanol from cellulose and concentrated on pretreatment, cellulase enzyme activity, saccharification, and concentration. The primary aim of pretreatment is to break down the cellulose by chemical or physical means to make it more susceptible to enzymatic hydrolysis. RAPAD results have demonstrated that a combination of chemical treatment and explosion can yield high rates of enzymatic conversion. RAPAD has also attempted to screen and develop strong cellulase-producing microorganisms to enhance enzymatic hydrolysis. Mutants of

*Trichoderma reesei* have been selected for further research. In addition, four new cellulase producers, including moulds and bacteria, have also been identified for further research.

To improve enzyme saccharification, RAPAD seeks to produce higher yields of glucose syrup in a shorter time. A continuous saccharification system that uses a low substrate concentration to obtain a high ratio of glucose conversion has been developed.

The research objectives for the fermentation process are to improve the technology for immobilizing yeast cells and to develop an efficient and highly productive fermentation system. RAPAD has developed an alginate-entrapped pilot system to immobilize yeast cells. In operation, the system has worked well. Because of the importance of the fermenter to the efficiency of ethanol conversion, RAPAD has examined fermentation systems and selected a fixed-bed, parallel-flow reactor that is used in conjunction with sheets of immobilized yeast cells. RAPAD was able to solve the problems of sludge adhesion to the yeast sheets and of contamination during fermentation.

## **Methane Fermentation**

Japanese research has shown that an immobilized methane-fermentation system improves the efficiency of methane fermentation by reducing the retention time from 16.9 d to 10.8 d and maintaining the same level of gas production. Conventional systems form the acid and gas in one batch, but the immobilized system ferments the methane in two phases (digestion or acid formation, and gasification or methane formation).

## **Microalgae Technology**

Microalgae are capable of direct synthesis of oil. These microalgae are produced commercially for high-value pharmaceuticals and health foods, but there is no technology developed for energy production from these organisms. The Japanese began to develop microalgae technology in 1980. Research has focused on increasing oil yields by species selection and improvement, but this process can



be lengthy. Another approach is to increase cell yield by improving the culturing process. The four common technologies for large-scale outdoor production of microalgae are the open bubbling method, the closed circulation method, the open circulation system, and the open sewage-circulation system. Japan is designing its own large-scale outdoor cultivation systems and must choose among an open or closed system, a shallow or deep system, and a synthetic or waste-products medium.

### **Utilization of Technologies and Systems Analysis**

The only significant biomass technology in commercial use in Japan is a program that pellets waste wood to produce briquettes for industrial purposes. The use of ethanol fuel has been studied, and tests have demonstrated that there is no difference between neat ethanol and gasoline.

A comparison of biochemical, thermochemical, and direct combustion technologies reveals that biochemical conversion for ethanol and methane production requires large quantities of raw materials that could be used at a lower cost for electricity generation or for direct combustion. Direct combustion is most feasible because the technology is simple and requires less raw material. Other systems require more research and development to become commercially feasible. The cost of the feedstock and the conversion technology are the major factors that affect the economics of these biomass systems.

### **Suggestions for Further Research**

Areas for further research in Japan include

- The production of liquid fuel from cellulosic biomass,
- The development of systems for local community use,
- The development of systems for international use,

- Cellulosic pretreatment, the establishment of a strong cellulase-producing culture, and the development of an energy-saving process to recover ethanol, and
- The development of a compact pelletizer, a compact gasifier, and gas- or solid-fuel generators to lessen the dependence of agriculture on fossil fuels.

# **Biomass Fuels and Health**

*Kirk R. Smith and Jamuna Ramakrishna*

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## **Overview**

This paper examines the health effects of indoor smoke produced by the burning of biomass in the households of developing countries. Although there are no specific studies comparing the health status of a population before and after the removal of smoke, enough information is available to draw some conclusions. The smoke emissions produced by the burning of biomass are described. Studies of the health impact of the smoke and its pollutants are reviewed. Recommendations are made for improving health conditions, assuming that a majority of the world's households will continue to burn biomass.

## **Analysis**

Air pollution can be measured from

- Fuel use, which provides a general indicator because pollutant release is roughly proportional to fuel use,
- Emissions monitoring, which is more accurate than measuring fuel use,
- Exposure monitoring, which takes into account concentration and duration and is usually the best and most practical measure for populations of any size, and
- Pollutant dose, which is the best indication but is relatively expensive to measure.

Smoke emissions are affected by fuel quality and the degree of incomplete combustion. When all of the organic matter in biomass is burned, essentially only carbon dioxide and water are emitted. The pollutants are not in the fuel; they are created during combustion. In small, simple domestic stoves, it is very difficult to achieve complete combustion.

The pollutants of concern in biomass smoke are suspended particulates, carbon monoxide, and hydrocarbons. The total suspended particulates (TSP) include inorganic carbon and a range of several hundred hydrocarbons, many of which can affect health. These toxic hydrocarbons, which exist in both gaseous and particulate form, include Benzo[a]pyrene (BaP) (the most studied of carcinogenic chemicals), acenaphthylene, and formaldehyde. Particulates from biomass combustion have toxicities that are similar to those of the particulates in the smoke from coal or diesel fuel.

A comparison of the emissions of common pollutants from several fuels indicates that small-scale biomass combustion produces higher emissions than fossil fuels. However, this does not prove that biomass combustion produces unacceptable pollution levels. Indoor concentrations are affected by such factors as fuelling rate, emission factor, ventilation rate, and room volume. Estimates of exposure include temporal and spatial factors. When air samplers are worn by cooks, a wide variation in exposures to common pollutants and BaP is observed. This is due to local weather and ventilation conditions. Generally, studies are inconclusive about the health impacts of exposure to indoor smoke because of the lack of data, inconsistent research techniques, the vast number of toxic pollutants to be studied, and the lack of comparative analysis with other pollutant exposures (for example, cigarette smoke). What seems clear is that a majority of the world's population in rural areas receives exposures and doses of major pollutants that exceed the levels experienced by their urban neighbours.

## **Health Risks**

Research on the health impact of the burning of biomass shows a link between domestic smoke and poor health. Risks can be divided into

noncancerous (respiratory abnormalities and acute respiratory infections) and cancerous risks.

Research in India, Nepal, and Papua New Guinea indicate that there is a link between respiratory abnormalities and symptoms and biomass smoke. More than 6 million children die each year from acute respiratory infections (ARI), and air pollution is a risk factor in ARI morbidity. In South Africa, a majority of respiratory problems in infants can be related to daily exposure to smoke. In Nepal, there is a positive correlation between ARI episodes and the amount of time that children spent near the fireplace. However, the suspected relationship between exposure to biomass smoke and cancer has not been established despite the large quantities of suspected carcinogens in some biomass smoke.

**Studies of Specific Pollutants** — Exposure to fossil-fuel combustion and cigarette smoke allows the study of two pollutants (carbon monoxide and particulates). Acute exposure to carbon monoxide can result in coma and death, and moderate short-term exposure can result in dizziness, headaches, and nausea. The long-term effects of lower exposures are not clear, but they are not likely to cause mortality although there is a growing link with impaired fetal development. Carbon monoxide may also increase the carcinogenic effects of other air pollutants. In addition, risk factors (for example, oxygen deprivation) increase sensitivity to exposure to carbon monoxide. In Guatemala, carbon monoxide exposure has a greater effect on people at higher elevations.

It is difficult to interpret the data on the impact of particulate exposure. It is easier to determine the health effects of acute exposure because there are more data than for chronic exposure. Acute exposures to fossil-fuel emissions show the joint effect of particulates and sulfur oxides (wood has a low concentration of sulfur oxides). Difficulties in controlling for compounding factors (for example, smoking and socioeconomic status) make many studies suspect. Nonetheless, there is reasonable certainty that acute exposures to the particulate pollution that is typical in rural kitchens of the developing world can increase both morbidity and mortality.

Polycyclic aromatic hydrocarbons (PAH) are organic compounds that are found in biomass smoke and are both mutagenic and carcinogenic. Although no link has been established between cancer and these compounds, there is much evidence of its carcinogenic potential.

## **Lessening the Impact of the Burning of Biomass**

Despite the dangers of exposure to biomass smoke, hundreds of millions of households will continue to burn biomass. The use of cleaner fuels, improved stoves, and better ventilation could lessen the negative effects of the burning of biomass. Some changes in behaviour could also help reduce exposure.

**Cleaner Fuels** — Some species of wood burn more cleanly than others, and dry wood burns more efficiently. Upgrading the biomass fuel can result in more dramatic improvements. Charcoal manufacturing creates most of the emissions of particulates and carbon monoxide. Total household exposure is lower, but overall pollution is the same or higher. Dung can be upgraded by anaerobic digestion, which yields biogas and fertilizer. Biogas emissions are similar to the emissions from natural gas. Vegetable oils can also be upgraded, and in some remote locations, they are economical as fuels. Alcohol fuels, derived from the fermentation of biomass, are thought to be clean burning.

**Improved Stoves and Better Ventilation** — There are many designs for stoves that promote higher thermal efficiencies and lower emission factors; however, global dissemination of improved stoves has been frustratingly slow despite many isolated successes. Problems that arise in the field but have not been considered in the laboratory include

- Lack of flexibility in variety of fuels and choice of cooking methods,
- Limited capability to accommodate a variety of utensils,

- The large area occupied by the stove in homes where space is limited, and in some cases,
- Continued high exposure to smoke because the stoves were not installed correctly, maintained adequately, or operated properly.

The thermal efficiency of stoves can be improved by controlling the airflow to increase the residence time of the flue gases. The efficiency of single-pothole stoves has been improved by using a grate, a reflective surface, a water jacket, and insulation.

Despite a lack of empirical data, improved ventilation is probably the least expensive short-term way to reduce smoke exposure. Three ways to improve ventilation are minor changes in the ventilation of existing structures, relocation of the kitchen, and major redesign of the kitchen.

**Behaviour Changes** — Changes in behaviour can help reduce the impact of exposure to biomass smoke without new technologies. These changes include moving the stove outdoors or to a verandah and keeping pregnant women and young children out of the cooking area as much as possible.

## **Costs of Exposure Control**

Generally, the three categories of policy tools that governments use to address pollution problems are

- Information (for example, government-sponsored R&D programs and rural education),
- The establishment and enforcement of ambient and emissions standards (generally, traditional regulatory approaches are ill-suited for domestic smoke pollution, but standards related to house and stove design may be relevant), and
- Economic tools that include severance taxes and subsidies (subsidies can be dangerous if poorly used because they create distortions and are expensive).

Cost-benefit analyses should include the costs of an increase in smoke exposure or the benefits of a decrease. The benefits of this type of pollution-control program might include decreases in medi-

cal care and in occupational disruption minus foregone benefits, such as the value of smoke as a form of thatch preservative. In the case of fuel savings, these benefits can be added to the benefits of reduced deforestation.

A rough analysis of the net present value (NPV) of the benefits of reduced exposure to domestic smoke selected as its benefit the reduction of chronic bronchitis in 10% of the population. Even without including the benefits of reduced ARI in children, decreased medical costs, decreased fuel costs, and increased household cleanliness, NPVs of more than 100 USD for most discount rates and degrees of impairment from exposure were found. This is more than enough to justify an improved cookstove program and investments in better ventilation and fuel.





**Volume 9**

**Human Energy**

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*Volume editor: Ashok V. Desai*

# **The Real Rural Energy Crisis: Women's Time**

*Irene Tinker*

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## **Overview**

Over the past decade, rural needs for energy have been equated with fuel needs alone. The mechanical or muscular energy used to produce and process crops and to survive has not been given due attention. When the time and human effort expended are analyzed, it becomes apparent that the main barrier to rural development is the scarcity of women's time.

## **Analysis**

Women's work in household and subsistence production is largely invisible to economic planners who focus on economic activity in the modern sector. Census statistics undervalue women's work in the agricultural and informal sectors. Basic survival tasks are defined as traditional household activities and are left out of economic tabulations because modernization is expected to eliminate them.

Data on women's economic roles have shown that poor women work more hours than men, the economic contributions of women (both monetary and nonmonetary) are absolutely essential to the survival of poor families, women's income (unlike men's) generally goes entirely to household needs, and water carrying and food processing are more sex-typed than fuel collection.

Time allocation research in villages in four different countries shows that women work 2–3 h more per day than men, the time spent fetching water is greater than the time needed for fuel collection, and food processing is by far the most time-consuming survival activity for women. Rural women are constrained by the inflexibility of their responsibilities to provide necessities for their families. Women are certainly not underemployed, but they are clearly underproductive.

The crisis in rural energy has been defined as a shortage of fuel and scarcity of firewood. The two solutions offered were to plant more trees and to introduce new stoves that either are more efficient for traditional fuels or use different energy sources. These solutions were not as widely successful as hoped because the problem was not perceived accurately, and the solutions required more time and effort from rural women who are already overworked.

The perception of the problem is gradually changing as patterns of supply and demand for energy are seen as part of the agrarian ecosystem. Firewood collected for cooking is only one small aspect of land degradation and deforestation. The major causes are clearing trees for new homesteads, logging in mountainous areas, overgrazing in Sahelian areas, and commercializing the production of firewood and charcoal to meet expanding urban demand.

There is now growing appreciation for the complex roles of forests and trees in the lives of rural residents. Social forestry programs have been adjusted to plant tree species that meet people's needs for fodder, fuel, fruit, and other edible products. However, reconciling local needs for forest products with commercial requirements for timber, building poles, and bullock cart wheels continues to be a major problem.

Similarly, early assumptions that traditional cooking methods were inefficient and that a single improved mud-stove could dramatically reduce fuel consumption have had to be revised in light of the experience gained in many stove programs. Rural women understand very well the tradeoff between fuel consumption and time saved. They adapt their cooking methods to their daily responsibilities and their families' needs.

Given the demands and conditions of women's lives in poor households, traditional stoves have proven difficult to replace. The requirement for cut wood for many of the new stoves, for example, implies not only more work for women but the need for an axe or other implement.

The idea of a universally applicable technology runs counter to the immense variability in culture, class, and ethnicity. If the unrealistic expectation that improved stoves offer a panacea for rural areas could be set aside, their importance could be seen more clearly. Improved stoves are more important for improving women's health by reducing smoke pollution than for reducing their workload.

The current focus on fuel issues is laudable but insufficient. Much more emphasis needs to be placed on reducing demands for human energy by introducing appropriate mechanical substitutes in ways that do not further impoverish women. Once the central energy problem of women's time is recognized, there may be other ways to address time and fuel constraints. Increased income, for example, will have a more immediate impact on these constraints than improved cooking stoves or new biogas digesters.

If the 2–3 h a day that women spend processing food were reduced, or the distance they walk to fetch water were shortened, then they would have more time to cook more carefully (and thus to conserve fuel) or to earn money to buy improved technology or fuels.

Planners must be alerted to the basic need to provide sufficient income for the poor to buy improved cooking stoves or higher grade fuel. They must recognize that constraints on rural women's time are central to development in general and to energy programs in particular.

For programs to succeed, people must perceive a need for the solution to the problem they address. Rural people in developing countries do not yet consider firewood a major problem. Development programs must involve both sides of the fuel–food equation, which is central to the survival of families in near-subsistence societies.

## **Suggestions for Further Research**

Research is needed on

- New stoves that meet the needs of households in developing countries and reduce the health hazards of smoke for women,
- Cooking methods that consider the health benefits of reduced smoke pollution and the time concerns of rural women in addition to the efficiency of fuel consumption,
- Low-energy food-processing techniques (the pretreatment or partial cooking of traditional grains could reduce the use of energy in the household),
- Alternative technologies for cooking needs (for example, solar heaters and biogas digesters),
- Activities in the informal sector (street foods should be recognized as a vital part of the urban scene rather than treated as an illegal eyesore),
- Microlevel aspects of rural energy to determine villagers' perspectives on how and where energy fits into the rural economy, and
- Gender in forestry projects, at both commercial and subsistence levels (women's traditional knowledge about forests, tree species, and uses of forest products should be better acknowledged and investigated, and more women should be involved as data collectors and extension agents to ensure that women's voices are heard).

# **Human Energetics**

*Grazia Borrini and Sheldon Margen*

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## **Overview**

The science of human energetics studies the human body as it consumes, transforms, and reproduces energy. It was developed through the application of concepts and principles of energy and energy flows to living organisms. Two main approaches to this science are explained.

## **Analysis**

Energy flow through the human organism can be treated as a purely mechanical phenomenon that follows the rule of energy conservation like any other physical system. In mechanistic terms, the body can be seen as a “rigid” user of energy that transforms food and radiation into heat and mechanical work at a fixed rate.

This approach to human energetics is a useful first approximation, but it does not explain phenomena such as homeostasis (regulation of the energy content of the body under different energy inputs and outputs) or the influence of socioenvironmental conditions and psychological factors on energy use by the body.

Energy flows in the human body can also be studied as the interaction between the human organism and its surroundings. In this approach, the context and the continuously changing response of the individual play the major role and offer the most meaningful information.

Whereas the first approach emphasizes measurable amounts of energy input and output, the second approach emphasizes variability and change in the energy flow and focuses on structure, process, and context. The combination of the two approaches offers a powerful tool for understanding human energetics.

In terms of measurable aspects of the energy flow through the human body, inputs of food and radiation and outputs of mechanical work and heat are mediated by the body's metabolism (the sum of an enormous number of microprocesses that transfer and use energy within the cells of the body). At the macroscopic level, metabolism is influenced by muscular activity, psychological state, drugs, physical properties of the environment, and dietary habits.

There is no generally valid relation between intake and expenditure. Energy intake of human subjects can vary from day to day and from week to week without significant fluctuation in body size or activity. Combined changes in dietary intake, muscular efficiency, and metabolic efficiency may account for homeostasis (the maintenance over time of body size and composition).

The Sukhatme–Margen hypothesis is a fundamental feature of a nonmechanistic model of energy interaction between the body and the environment. This hypothesis states that the body can maintain homeostasis within a wide range of energy intakes. Interaction between the body and its environment is regulated by factors intrinsic to the individual, its unique genetic background and development, and its variable environment (Sukhatme and Margen 1982).

The quantification of energy requirements for individuals is called into question on the basis of several issues, both empirical and theoretical. Energy requirement, as referred to by the Food and Agriculture Organization of the United Nations (FAO), is that energy intake able to meet the needs of an average individual of defined sex, age, health status, and activity level. It is assumed that the quantity of food eaten by healthy people living a normal life represents their requirement.

Rather than requiring a single fixed value of energy intake, an individual's energy balance is regulated in a flexible way by a continuously changing interaction with the environment. The capac-



ity for regulation varies widely for an individual and among individuals.

The most important product of the flow of energy through the human body is not work output but the process of life. The relation between energy intake and work output must be considered within the context of the biological and cultural environment of each community. This relation also involves political and ethical considerations. Better health and nutrition should be promoted because they are, first of all, good in themselves.

Energy needs, means, and wants are shaped by the local environmental, social, and cultural reality. The context is essential to define energy requirements and assess whether these requirements are being met. A more appropriate definition of energy requirements would allow planners to direct resources toward more productive interventions and to target feeding programs to those who need them the most.

The human body, behaviour, and culture exhibit a flexible energy interaction with the environment. This flexibility should be carefully managed to protect the interests of the individual and the community. Because energy requirement is both a biological and a political issue, the roles of researchers and experts should be changed. Rather than directing research processes to understand, define, and make decisions, they should be providing resources to the community to allow it to achieve its own goals.

Full advantage could then be taken of our understanding of the complexity of human energetics. Concepts such as "fixed energy requirements" that are divorced from context and values should be renounced. Energy needs can best be defined in the process of community organization and should involve not only bread, but dignity and justice.

## **Suggestions for Further Research**

Research should seek to understand

- The processes of energy regulation and adaptation, with particular reference to variations in energy intake,

- The degree to which genetics and the environment control energy regulation, and
- The nature of functional changes involved in energy regulation and adaptation.

The most important research recommendation is that the people for whom research is being carried out be involved in the research process.



**Volume 10**

**Energy Planning:  
Models, Information  
Systems, Research,  
and Development**

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*Volume editor: Amulya Reddy*

# **Energy Models**

*B. Lapillone, P. Criqui, and J. Girod*

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## **Overview**

This paper reviews three types of developments in energy modeling. First, econometric models were enhanced to offer a more realistic representation of energy demand and the economic forces that shape it. Second, technoeconomic or energy end-use models were developed as an alternative approach to explain and forecast energy demand. Third, a number of global energy models were built to incorporate the supply and demand of resources into a multiregional framework of analysis. Some of the criticisms directed at energy models are reviewed, and suggestions are made on how modelers and their models could better serve the users of these analytic tools.

## **Analysis**

Before the oil crises of the 1970s, economic output and energy demand underwent regular and rapid growth. It was, therefore, acceptable for energy agencies and companies to work with rudimentary energy models that related energy demand to GDP, sectoral value added, and in some cases, energy prices.

After these oil crises, it became apparent that such simplified econometric models could not explain the factors affecting energy demand, assess the potential impacts of policy measures, or forecast the future growth and pattern of energy demand.

## Econometric Models

Econometric models use economic indicators (for example, GDP, sectoral output or income, and energy prices) to determine the level of energy demand, in total or by sector or form of energy. In the most common models, the variable coefficients of output and price represent the elasticities of demand with respect to output and price.

Traditional econometric models have several limitations. Price elasticities are difficult to measure, and they exhibit a wide range of values. Their role may also be overemphasized because nonprice factors (for example, conservation programs and efficiency standards) are ignored in these models. Other weaknesses for forecasting include the potential asymmetry between changes in demand caused by a decrease or an increase in prices, and the influence of anticipated and marginal prices (not just average prices) on consumer behaviour. Output or income effects may also be modeled inadequately if there is insufficient disaggregation by economic sector (to show impacts of structural change) or by income group (to show impacts of patterns of income growth).

To overcome these problems, econometric models have become more disaggregated, and they are limited only by the availability of sufficient historical data on the required indicators. Knowledge of price effects has been enhanced by considering both short- and long-term responses to price changes and by allowing elasticities to vary according to the level or rate of change of prices. Finally, more complex models have been built to account for the impacts of capital stocks on energy demand. These models include structural models in which demand is shaped by either the energy efficiency and rate of use of capital stock, or KLEM models, which use production functions to estimate substitution effects among factors of production, including energy.

## Technoeconomic (End-Use) Models

Technoeconomic models provide details of the end uses of energy in each of several energy-consuming sectors. They also provide detailed calculations of useful (output) and final (input) energy needs

for each end use and sector. End-use models can be used to evaluate demand management and fuel-switching possibilities because they distinguish between useful energy (for example, space heating needs) and final energy (for example, the consumption of oil, natural gas, or electricity) and account for losses due to energy conversion. This modeling approach needs detailed data on end-use coefficients (for example, useful heat energy required per unit of floor area), efficiencies of energy conversion (for example, boiler efficiency), and the stock of energy-consuming units (for example, floor area by type of building or sector).

Accounting models were the simplest and earliest forms of end-use models. Most of the model variables are exogenous (determined outside the model), and the model serves as an accounting tool. The principal advantages of the model are its realism and degree of detail. These models can simulate the impacts of alternative energy policies and programs on fuel- and sector-specific energy demand and the potential for energy conservation and interfuel substitution. End-use models can also be used to develop and analyze detailed balances of energy supply and demand. The disadvantages of these models are that the large quantity of detailed energy and technical data may be difficult and costly to obtain, energy prices are not explicitly considered, and the need for many exogenous assumptions may lead to scenarios that are internally inconsistent.

Technoeconomic models have been improved to explicitly consider price effects. A common enhancement is the incorporation of submodels of market shares that allocate total useful energy needs to competing (present or future) energy forms. These submodels determine fuel-specific shares for each end use on the basis of relative life-cycle costs, which in turn are based on equipment costs and efficiencies, energy prices, the cost of capital, tax rates, and investment incentives (for example, capital grants).

## **Global Energy Models**

Concern about the depletion of nonrenewable resources and shocks in petroleum prices led to the development of global energy models. Three regionally disaggregated supply-demand models were devel-

oped by the Workshop on Alternative Energy Strategies (WAES) headed by the International Institute of Applied Systems Analysis (IIASA), the Massachusetts Institute of Technology, and the World Energy Conference (WEC). All three models considered the long-term balance of resource supply and energy demand in five to eight regions of the world. However, each had a particular focus. The WAES model focused on the substitution of coal for oil; the IIASA model, on the long-term prospects for nuclear energy; and the WEC model, on the impact that the rising energy demand from developing countries would have on oil markets. Other global models, such as the Energy Modeling Forum (EMF) and Choe's World Bank model, were designed to deal specifically with petroleum markets. Unlike the other three global models, the oil-market models addressed, albeit incompletely, the issue of energy-economy interactions. Global energy models could be enhanced if world energy data were improved and the importance of links between energy models and macroeconomic models were recognized.

## **Using Energy Models**

There is no single modeling approach for all situations. The choice depends on objectives, the required degree of analytic detail, data availability, and time and budget constraints. Some general guidelines for modelers who want to enhance the usefulness of their models for decision-makers in the energy sector are

- Build as simple models as possible because complex models are increasingly mistrusted,
- Build conceptual and qualitative models, not just quantitative models,
- Use models not only to forecast, but to make and review decisions, and
- Fit models into a single structure to enable users to move from simple energy balances to energy analysis, forecasting, and planning.



# **Energy Modeling in Developing Countries**

*Jean-Guy Devezeaux de Lavergne*

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## **Overview**

This paper describes some of the features of developing countries that are relevant to energy modeling, provides an overview of what is meant by energy modeling, summarizes the features of different types of demand, supply, and global models, and suggests ways to improve the design and use of these models.

## **Analysis**

The energy sector plays several important roles in the economic activity of developing countries. Energy commodities are an input into the production of goods and services. Energy is a final consumption good that provides cooking, transportation, and other services. The energy sector also contributes to GDP and affects trade balances and the balance of payments. Therefore, there is great interest in modeling energy demand, energy supply, and energy-economy interactions.

## **Relevant Characteristics of Developing Countries**

Developing countries share a number of economic and energy characteristics that affect energy modeling. Economic traits include

- Rapid population growth and low educational standards,
- High degrees of central planning,
- Regulated and constrained domestic markets,
- Significant traditional (agricultural and artisanal) sectors,
- Narrowly specialized economic structures and production,
- Constrained levels of capital and investment, and
- Weak currencies.

Energy characteristics shared by most developing countries include a lack of understanding of the concepts of energy planning, a scarcity of reliable long-term statistical data, and the importance of noncommercial energy (more than 90% in many developing countries). Despite these similarities, there are sufficient differences among developing countries to argue against the use of a single multicountry model. There are differences in the level of development, technical know-how, geographic size, and degree of openness of the economy. As well, the majority of energy-importing countries face different issues than the energy-exporting countries, and indigenous energy supplies vary among developing nations. These economic and energy features must be taken into account by energy models.

## **Energy Modeling**

A model is a set of equations that represents the real world. Although both the data and the theory underlying the model may be imperfect, models are important tools. They can be used to plan and analyze the economic and energy impacts of policies and external events and to assess competing technologies that supply energy. Energy models are either hierarchical (open-loop) or global (closed-loop). Open-loop models use economic indicators as exogenous variables to define energy demand but do not include feedback from the energy sector to the rest of the economy. In contrast, closed-loop models consider the two-way interaction between energy and economic variables. The level of economic activity influences energy demand, which in turn affects the economy.

## **Hierarchical Demand Models**

One-sector models use ratio analysis (energy demand per unit of output) and statistical time-series analysis to determine sectoral energy demand. This approach is simple, but this simplicity is also a limitation because the models consider neither substitutions among various energy forms, nor changes in the structure of the economy.

Multisector models overcome some of these problems. They distinguish between the traditional and modern sectors (for example, Parikh's model of India — Parikh 1976; Parikh and Srinivasan 1977), among several economic sectors (for example, Resources for the Future), and among sectors and end uses of energy (for example, the MEDEE model — *Modèle d'évolution de la demande d'énergie*). All of these approaches are useful because they are relatively simple to develop and understand, and they provide a better understanding of the energy system than one-sector models. But they are not without limitations. They ignore price effects, lack a macroeconomic forecasting framework, and do not provide sufficient treatment of inertias and time lags. One way to enhance the macroeconomic coherence of open-loop models is to use input-output (IO) tables. The World Bank's MSEDm (Minimum Standard Energy Demand Model), for example, uses IO tables to convert final demand into gross output and demand for various energy forms.

## **Hierarchical Supply Models**

Linear programming models are the oldest optimization models. They were used initially to develop least-cost investment plans in the power sector (for example, the WASP — Wein Automatic System Planning Package — dynamic linear program). More recently, the models have been combined with IO tables to compute alternative and minimum-cost investment plans for the energy sector as a whole. Two limitations of these models are that the data used are more technological than economic and that IO tables embody fixed technical coefficients that must be (but are seldom) updated regularly.

## Global Models

Global models of supply and demand incorporate feedback from the energy sector (particularly price effects) into the macroeconomy. Global models of supply can be used to assess the price at which a given energy technology becomes feasible and to determine the impact of changes in energy prices on energy supply industries and on various macroeconomic indicators. Global models of demand (for example, Mukherjee's (1981) energy-economy model) combine demand functions with macroeconomic production functions to trace the effects of exogenous changes (for example, energy prices) on energy demand and economic variables (for example, capacity utilization, aggregate prices, and domestic energy prices). A feedback loop is used to start the next iteration, which determines the impact of energy prices on energy demand and the economy. The lack of an integrated energy demand-supply block, especially with regard to investment requirements, is the main limitation of these models. An extension of Mukherjee's model (SIMA, Simulation of Macroeconomic Scenarios to Assess Energy Demand) was an early attempt to build an integrated supply-demand tool.

## Suggestions for Further Research

These models can be adapted for use in most developing countries. To enhance the applicability of the models, several things are needed:

- Better data collection because lack of data is the main problem in energy modeling,
- Improvements in the structure of demand models to include additional price variables, the traditional (noncommercial) sector, and emerging types of energy commodities,
- Use of a coherent set of exogenous values,
- Improvements in the models to include monetary and financial variables (for example, interest and exchange rates), and
- Expansion of the supply models to include noncommercial and renewable energy and the impact that the use of these forms of energy has on the environment.

# **A Framework for Establishing Energy Research and Development Policy in Developing Countries**

*Mohan Munasinghe*

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## **Overview**

Energy R&D has become a big business, especially since the price crises of 1973 and 1979. Therefore, it is essential, especially when national financial and human resources are scarce, to establish a logical and sensible approach to allocating funds and effort to energy R&D. This approach is facilitated in most developing countries because the impetus for R&D is the responsibility of the central government. This paper develops a rational and systematic framework, as well as relevant criteria, that can be used to help determine policies and priorities for R&D in any developing country.

## **Analysis**

The process for the development of an R&D policy for energy is straightforward and consists of five steps.

### **Step 1**

From a comprehensive list of energy R&D topics, select a subset that is most pertinent to the immediate needs, medium-term development goals, and long-term aspirations of the nation (in that order of priority). This step is guided by a thorough assessment of the coun-

try's resource endowment, its fiscal position and outlook, financial characteristics, and the technologies and options available.

## Step 2

Evaluate the topics in this subset using a simple formula that is designed to calculate the net expected benefits (or economic efficiency) of each topic:

$$NB = B(R\&D) - C(R\&D) + B(IMPLEMENT) - C(IMPLEMENT)$$

where NB is the calculated net benefit of the R&D undertaking,  $B(R\&D)$  is the present discounted value (or present value, PV) (see endnote 1) of the stream of benefits accruing from the R&D undertaking,  $C(R\&D)$  is the PV of the costs of the undertaking,  $B(IMPLEMENT)$  is the PV of the benefits derived from implementing the results of the R&D project, and  $C(IMPLEMENT)$  is the PV of the costs of implementation.

All costs and benefits are expressed in terms of their economic, not market, value. The "price" of a cost or benefit is its highest value when used for some purpose other than for the project in question. Care must be taken in the selection of appropriate values (often called "shadow prices") because costs are usually more readily identified than benefits and long times are involved.

## Step 3

Rank each R&D option according to its net expected benefit to the nation (economic efficiency). Because of the uncertainties inherent in each option, it is prudent to test the results of the efficiency calculation by altering an assumption on which a cost(s) or benefit(s) is based and then redoing the calculation. The most robust option over the range of scenarios should rank first.

## Step 4

Consider, in advance, the constraints to implementation of the R&D program. These can include any combination of

- Lack of financial, physical, or human (skills and training) resources,

- Institutional barriers (for example, a lack of specialized knowledge on the part of decision-makers or their advisors, an absence of coordination among the various levels of government or between the relevant government agents and the private sector, and inadequate links between the nation's policymakers and foreign or international sources of funds or expertise), and
- Policy constraints, engendered by a weak or nonexistent national energy plan or planning process.

## **Step 5**

Set in motion processes that can overcome these obstacles. Increase local contributions where potentially available (for example, from power utilities and oil, gas, and coal extraction companies, especially if these are government owned). Consider taxes on energy imports and allocate the proceeds to a fund for energy R&D. Appraise domestic and foreign financial institutions of the potential for short-term investment gains from preferential loans for R&D purposes. Investigate the availability of export assistance, grants, and loans from countries that possess some of the technology that is necessary to undertake the R&D or to implement the technology that is likely to be produced. Human resources must be protected by offering attractive salaries or other perquisites. As well, skilled personnel require access to information and equipment to carry out their work. Providing these inputs may be more efficient in the long run than purchasing the skills and resources of foreign consultants.

A lack of understanding of the relevant energy issues can be overcome with education campaigns aimed at both decision-makers and members of the energy-consuming public. Interactions of the national government with foreign governments, international aid institutions, and multinational enterprises and organizations must be established, strengthened, and stabilized.

The coordination of policy and planning must begin with a conscious effort to bring together the various levels of government that are involved in energy planning and related areas (the environment, financial institutions, and fiscal, monetary, and budget policy).

## Notes

1. Calculated as follows:

$$B(R\&D) = \sum_{t=0}^T B(R\&D)_t / (1+r)^t$$

where  $B(R\&D)$  represents the benefits of the R&D activity in year  $t$ ,  $T$  is the overall time horizon in number of years, and  $r$  is the selected discount rate.



# **Information Systems for Energy Planning and Management**

*Oliviero Bernardini*

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## **Overview**

This paper sets out the parameters of a general approach to establishing a country-specific tool for energy policy and planning. This is a large undertaking that requires a substantial commitment of national resources. But, unlike specialized consultants who provide similar information on a “one-off” basis, the resulting policy and planning tool will contribute to the long-term effectiveness of government planning institutions and, hopefully, to the efficiency of the economy.

## **Analysis**

Policy analysts and energy planners are increasingly aware that the real problem when developing information systems for energy planning is not the modeling system. Rather, the challenge is to find the most appropriate resolution, system structure, and configuration for the problem and to choose the most appropriate objective function, given the data available on energy supply and demand.

A number of “off the shelf” evaluation models have been developed since the oil crises highlighted the need for comprehensive energy planning. Although these models have helped industrialized nations make decisions on their energy policies, repeated efforts to

fit the special energy problems of developing nations to these models have been futile. Variability in energy systems, energy decision functions, and available information effectively limit the application of generalized systems to data management and core computer packages (for example, regression analysis, linear programming, and matrix inversion).

Consequently, the best approach when examining the situation in any given developing country is, in effect, to build a tool for energy information, policy, and planning from the ground up. The three key components of this tool are management, information, and modeling.

## **Management**

The most efficient and productive way to set up an information system is to involve future users of the tool in every stage of its construction. This includes the critically important, but admittedly tedious, task of gathering microlevel information (consumer surveys and fieldwork), organizing the data into a useable (computer compatible) form, and defining the model that will analyze the data and produce report-ready output.

The energy planning tool must be managed according to the specific circumstances of the country to ensure that it is used to its maximum advantage. First, the size of the energy delivery system(s) determines, to a large extent, the degree of risk involved in committing resources to any project. Small systems take on more risk than large systems when a single, large project is added. Integrated systems face smaller risks when any kind of new supply is added. Second, the information produced by the planning tool must be in a form that meshes with the decision-making structure. If local energy planning is established, planning and policy information in the national context may be of little use. Third, the possibility of fuel substitution and conservation must be taken into account (with a sufficiently high degree of resolution) to ensure that the information provided by planners is supplied in the appropriate context.

## **The Information Set**

The lack of information for energy planning in developing countries is a major handicap. Energy systems rely largely on traditional fuels, and their supply and demand vary from location to location across the country. The energy market can, in any given country, be fragmented into several regions, which makes aggregation to the national level difficult and potentially meaningless for policy and planning purposes. Therefore, it is necessary to undertake regional analyses of energy balances (consumption and production) and to orient policymaking accordingly. Because great detail is involved in this approach, much effort, in terms of both person hours and financial resources, is required.

Data on energy consumption can only be acquired by ground-level surveys. This is because, depending on the nation in question, up to 95% of primary energy consumption is of fuelwood or other traditional energy sources. The “market” for these energy resources is almost always local, and it must be estimated from local indicators of supply and demand. For this survey to be representative, a large number of households and fuel suppliers must be included.

Data on energy production (including imports) are often equally difficult to obtain, but advances in technology have improved their reliability and coverage. For example, satellite maps that depict the location of biomass resources (on which so much of the developing world relies) have been available since the early 1970s. The information on these maps must be locally calibrated, which involves ground-level verification, often over vast expanses of territory. The wealth of information made available is well worth the effort.

Once the data are collected, they must be organized and used as soon as possible. If too much time passes, the risk increases that when the information is finally analyzed it will yield results that are out of date when compared with the current, constantly evolving local, regional, national, and global energy markets.

## Modeling Decision-Making

**Supply** — The general rule when selecting from among various supply options is that the net present value (NPV) of benefits accruing from the decision option is positive (see endnote 1). There are, in addition, two evaluation approaches that are more financial (rather than economic) in perspective. The “payback period” (PBT) assesses the relative profitability of a project, which is defined as the number of years required to recover the investment costs of a project from its cash flow. In NPV terms, this is the number of years required to achieve a net present value of zero (see endnote 2). This approach is only useful if calculated paybacks are short (2 years or less indicates a good project) or very long (20 years or more indicates a poor investment). Uncertainty over intermediate times means that a more sophisticated tool must be used.

When the service produced by the investment is a fuel or energy flow, the “levelized cost” of the energy produced (or consumption avoided) can be computed. This is the “price” that must be charged to recover the total cash flow within the lifetime of the project. The levelized cost is the product of the capital recovery factor (CRF) and the present value of total costs (PVC) (see endnote 3).

Most project evaluations are based on the “internal rate of return” (IRR), which, like payback period, is calculated using the concept of discounting. The IRR is the discount rate that, when applied to a stream of benefits and costs reflected in the cash flow of a project, produces a NPV of zero (see endnote 4). Projects are generally acceptable when the IRR is greater than the accounting rate of interest (banking rate). The greater the rate of return, the more acceptable the project because a greater NPV of benefits will accrue from the investment.

**Demand** — Attempts to model energy decision-making by households have generally used econometric techniques. These methods are useful, but they can oversimplify actual consumer decision-making, especially in a dynamic context. A more appropriate approach might be to treat consumer decision-making as a simple accounting

problem, in which consumers base their energy decisions on the capital cost of equipment (including subsidies and other policy incentives), the relative out-of-pocket costs of fuel alternatives, and an appropriate discount rate. Aggregation of the demand functions for a given population yields a target for the purpose of planning energy supply.

These classical approaches to project evaluation may appear simple. However, in practice they require a comprehensive understanding of the environmental, technical, economic, and financial factors that can affect the outcome of a decision and its long-term consequences.

## Notes

1. Calculated as follows:

$$NPV = \sum_{t=0}^T (B_{(t)} - C_{(t)}) / (1 + r)^t$$

where  $B$  is benefits in year  $t$ ,  $C$  is costs in year  $t$ ,  $T$  is the over all time horizon in number of years, and  $r$  is the selected discount rate.

2. Calculated as follows:

$$PBT \sum_{t=0} (B_{(t)} - C_{(t)}) / (1 + r)^t = 0$$

where  $B$  is the benefit of the project in year  $t$ ,  $C$  is the cost in that year, PBT is the payback time in years, and  $r$  is the selected discount rate.

3.  $CRF = r / [(1 - (1 + r)^{-T})]$ , where  $T$  is the lifetime of the project, and

$$PVC = \sum_t^T TC_{(t)} / (1 + r)^t$$

where  $TC$  is the total cost in year  $t$ ,  $T$  is the overall time horizon in years, and  $r$  is the selected discount rate.

4. Calculated as follows:

$$NPV = \sum_{t=0}^T (B_{(t)} - C_{(t)}) / (1 + r)^{IRR} = 0$$

where  $B$ ,  $C$ ,  $T$ ,  $t$ , and  $r$  are as defined in endnote 1, and IRR is the internal rate of return.



**Volume 11**

# **Energy in Africa**

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*Volume editor: Djibril Fall*



# **Energy in West Africa**

*Adam Kahane and Silas Lwakabamba*

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## **Overview**

This paper reviews patterns of energy supply and consumption in West Africa. Eleven of the 15 countries in West Africa (Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, and Sierra Leone) are surveyed. A consistent energy account of the region to the mid-1980s is presented. Data were drawn from a variety of sources (for example, the International Bank for Reconstruction and Development (IBRD), UNDP, and the United States Agency for International Development (USAID)).

## **Analysis**

### **Primary Energy Resources and Production**

Stocks of oil, gas, coal, and uranium, biomass, and sunlight and water are substantial but unevenly distributed throughout the region. Among commercial sources, proven oil reserves are found in seven countries, but only the four largest reserves are producing. In 1984, Nigeria produced 90% of the total oil output of the region. Data on proven reserves of gas, coal, and uranium have been gathered, although none of these resources are produced or marketed in significant quantities. Production can be important in other ways. For example, Niger produced only 4 500 t of uranium in 1981, but

uranium made the largest contribution to the country's export earnings. Although hydroelectricity is widely distributed and technical appraisals are positive, economic appraisals have put many proposals on hold because of such factors as cost, low demand, or regional riparian rights related to flooding and irrigation.

Fuelwood is the most widely used energy resource, and it is under great pressure because of deforestation. The situation is in crisis proportions in local, selected areas in most countries. Only Ghana and Liberia do not have a national deficit in fuelwood. Unfortunately, research on the issue has been qualitative, and hard data are lacking. Reports suggest that consumption exceeds stock growth by 50–200%. Widespread erosion and loss of agricultural productivity are associated problems.

## **Secondary Energy Production**

Electricity, charcoal, and refined petroleum are secondary fuels in the region. All countries use thermal generators, and most have hydroelectric generators. Estimates of the amount of wood used for consumption for charcoal production vary from 10 to 30% of total fuelwood harvests. There are 10 refineries in seven countries.

## **Energy Trade**

In energy terms, the net balance of trade in commercial fuels is negative for all but three countries. Imports of petroleum have increased and now consume an important share of export earnings.

## **Energy Consumption**

Consumption is characterized by the predominance of wood and petroleum. As in most developing nations, wood is the predominant fuel in the household sector. Wood (or charcoal) is used mainly for cooking. Accurate data on wood consumption are lacking. Consumption of an important biomass fuel, agricultural residues, is not discussed.

The largest consumers of petroleum are the two oil-exporting countries, Cameroon and Nigeria. The transportation sector gener-

ally consumes more than 50% of all petroleum products; electricity generation takes up a sizeable share in Liberia, Niger, and Senegal; and the residential sector generally uses less than 15% of the total.

Typical of most developing countries, wood is the primary fuel for rural households. There is greater variation in urban households, which use kerosene, electricity, and liquefied petroleum gas. Programs that promote efficient woodstoves have made important inroads in the region. The transportation sector is generally the greatest consumer of petroleum products, and conservation is recognized as being important in all countries. Despite this recognition, limited research and conservation programs have been undertaken. Data are inadequate on consumption in the industrial sector. Industry consumes a major portion of electricity, particularly in those countries with mining and smelting activities (for example, Cameroon, Ghana, Liberia, and Niger). Little information is available on efforts to conserve industrial energy.

## **Suggestions for Further Research**

Research is needed to

- Identify patterns of wood and charcoal consumption and use these to develop fuelwood policies to supplement supply (forestry and agroforestry approaches to reforestation) and promote efficiency and conservation (fuel substitution, stove, and charcoal-kiln improvements),
- Analyze energy options (for example, the neglected areas of solar, wind, agricultural residues, and efficiency) using standard methodologies that allow consistent comparisons among all energy forms, and review national energy policies to determine the impacts of energy pricing and capital subsidies,
- Identify the institutional and management issues in the energy sector and the impact that government planning has on coordination and efficiency within the sector,
- Survey energy resources (in some countries),

- Improve consumption data and link disaggregated patterns of subsectoral consumption to demographic and other socioeconomic information to improve the forecasting of energy demand and to effect policies that will influence that demand, and
- Expand efforts to conserve petroleum fuels in the transportation and electricity sectors and document efforts and opportunities to conserve commercial fuels in the industrial sector.

# **Energy in East Africa: Consumers and Resources**

*Phil O'Keefe*

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## **Overview**

The energy accounts of three East African nations (Kenya, Tanzania, and Uganda) are provided. Social and economic characteristics (with supporting data) are related to patterns of energy supply and demand. Energy options for the region are discussed, and policy and research recommendations are made.

## **Analysis**

The socioeconomic characteristics of these countries are related to energy demand. Factors as diverse as employment, natural resource endowment, population growth, demographics, and agricultural practices are reviewed. Population growth is high in the region. Despite this, given the subsistence farming production systems, East Africa is underpopulated. The current energy crisis in East Africa cannot be blamed only on population growth.

Consumption patterns and supply sources for energy show a reliance on biomass fuels, particularly in rural households. Overall, final use of biomass (fuelwood, charcoal, and agricultural residue) constitutes 71% of total energy consumption in Kenya, 91% in Tanzania, and 70% in Uganda. Charcoal is growing in importance as populations shift to urban areas and transportation costs from reced-

ing forest areas increase. Although petroleum fuels are a minor contributor to energy supply, they are significant because they are the largest component of commercial fuels and they require large inputs of foreign exchange. The transportation sector consumes about half of all petroleum. Petroleum generates most of Kenya's electricity; hydroelectricity predominates in Tanzania and Uganda.

## **Options for Supply**

Nuclear power is currently technically and economically inappropriate for East Africa. Minimum reactor capacities would imbalance the system and make the system vulnerable to overload. Technological adaptations to smaller capacity reactors hold promise. Coal is suggested as a bridging fuel even if it must be imported, but the environmental issues of these two fuels must be addressed. Indigenous exploration and identification of coal reserves have been inadequate to date. New and renewable sources of energy are considered inappropriate because of the lack of a sophisticated energy infrastructure. This lack of infrastructure is a major obstacle to change, especially managed change. Development of these technologies is best left to developed economies.

The industrial and transportation sectors are the major users of commercial energy. The economies of East Africa already have enforced energy conservation by rationing (whether planned and government controlled or because of financial barriers). These countries receive technology on a turnkey basis; therefore, until efficiency changes are made in developed nations they will not be readily adaptable to East Africa. Money spent on energy efficiency is, therefore, often wasted. Efforts would be better focused on more and better research into the conservation of fuelwood using improved cookstoves. The multiple uses of the open fire for space heat, maintenance of thatch, and preserving and flavouring food have been neglected in favour of a focus on cooking. This has led to notable failures of improved design programs.

The energy policies developed by governments in recent years have been similar. Although Kenya has created a ministry of energy,

and Tanzania and Uganda have not, their broad responses have meant that

- Pricing policies are such that oil costs have been passed on directly to the consumer, electricity has been priced below its marginal cost of production, and fuelwood has been priced to give a comparative advantage to urban consumers,
- Petroleum taxation has not kept pace with inflation, which means there is an implicit government subsidy,
- Capital allocations for new projects have been made mainly in the electricity sector, and
- Education and training have received comparatively little spending.

### **Suggestions for Further Research**

The energy future of East Africa over the next 20 years remains one of oil and wood. Therefore, research should

- Focus on enhancing biomass supply by investigating opportunities to produce fuel from the tropical high forests, large-scale mechanized monoculture to produce fuel pellets, the accelerated transition of biomass from a free good to a cash crop in high-potential areas, options for agroforestry in the medium-potential areas, and the introduction of energy plantations (especially charcoal in low-potential areas),
- Investigate coal as a bridging fuel, and devote resources to geologic research to determine reserve potential, and
- Devote resources to strengthening the administrative capacity of governments to handle petroleum and wood issues, which in the past have been within the purview of private capital and agricultural administrators, respectively.

It is important that resources not be squandered trying to develop technology and alternative energy sources if their promise for the future is marginal or unproven.

# **Wood Fuels: The Past and Future for East African Energy**

*Bariki K. Kaale*

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## **Overview**

A brief review of 1980 energy supply–demand data for three countries in East Africa (Kenya, Tanzania, and Uganda) reveals their heavy dependence on fuelwood (69% in Kenya, 90% in Tanzania, and 91% in Uganda). The key role of fuelwood is discussed.

## **Analysis**

Within the total pattern of supply and demand, fuelwood predominates in Kenya, Tanzania, and Uganda. Petroleum will not likely increase its limited share of energy supply because of restrictions on access to foreign capital. Other indigenous resources (hydroelectricity, natural gas, and coal) are available, but they do not play an important role. The market for these resources is small, and there is inadequate infrastructure for extraction and generation, distribution, and end-use conversion.

A comparison of energy projects in the region illustrates that there is an imbalance in priorities between developing fuelwood and other commercial fuels. The Kiambere hydroelectric project (140 MW) in Kenya is expected to cost 500 million USD (80% of which is foreign currency) and supply 0.5% of Kenya's energy by the year 2000. A project to establish 1.4 million ha of trees on



farmland is expected to cost 300 million USD (85% of which is local currency) and supply 35% of Kenya's energy by the year 2000.

## **Fuelwood Supplies and Consumption**

Data on the supply and consumption of fuelwood depend on detailed surveys. Most surveys have been uneven in their methods and results because there is no standardized methodology. Complex socio-economic, cultural, and ecological interactions affect the harvesting and consumption of fuelwood. Other factors include geographic and administrative zones and the local effects of land use.

Natural woodlands, mainly scattered trees and shrubs, provide most of the fuelwood (up to 70%). Cultivated trees on farmland are also an important source, especially in areas of high population density and intensive agriculture. Manual collection is the usual method; therefore, accessibility is approximately within a radius of 10 km. Plantations play a minor role in fuelwood supply and serve mainly industrial interests.

Data on domestic consumption are uneven. Consumption ranges from 1 to 4 m<sup>3</sup> per person and is influenced by availability of wood, climatic conditions, cooking habits, and end-use efficiencies. About 15% of fuelwood is used for nondomestic purposes (mainly brewing).

Scarcity of fuelwood is a serious problem in Kenya and Tanzania. Nationally, these countries are harvesting well above (Kenya 170%, Tanzania 150%) the level that can be sustained annually without depleting the current stock and degrading the environment. One region of Tanzania shows a 2 120% depletion rate! With population growth rates of 3–4%, the demand for fuelwood will intensify. Forecasts for Africa estimate an annual increase in demand of 5%. The impacts of fuelwood shortages in East Africa are mainly anecdotal and have not been researched, but they likely include wasted productive labour because of increased collection time, loss of soil nutrients because of the use of dung and agricultural residue as fuel, the need for the poor to purchase fuelwood, and a decline in nutrition due to changes in diet.

## Charcoal

The higher energy density of charcoal compared with wood makes it a more cost-effective fuel if the source of wood is some distance from the centre of consumption. Charcoal is also a more convenient, cleaner burning fuel that provides a superior cooking heat.

About 95% of charcoal is produced in earth kilns, either in a pit or from a “mould” above ground. Although these kilns are easy and inexpensive to construct, their return is poor when compared with commercial kilns made of metal or brick. Earth kilns produce returns of 10–15% by weight, whereas metal and brick kilns can return up to 25 and 30%, respectively. The advantages and disadvantages of each type of kiln are presented. Research suggests that brick kilns are the most effective method of charcoal production because they have low capital costs and moderate labour requirements. Brick kilns are likely to play an important role in the region, particularly on fuelwood plantations. Attempts to extend the use of hardwood charcoal by densifying and briquetting softwood charcoal, charcoal fines, logging residue, and agricultural waste from coffee, rice, and cashews have been inconclusive.

## Alternatives

A cost–performance comparison (USD per energy unit) shows that wood and charcoal have few competitors: wood (15% moisture content) 1.2, charcoal 2.9, biogas 7.0, kerosene 8.3, butane 13.6, and electricity 21.9. The difficulties encountered when trying to introduce improved wood stoves for cooking suggests that charcoal stoves have greater promise for conservation because they are used primarily for cooking in nearly 85% of urban dwellings. Although the replacement of oil (through gasification, steam engines, and dendrothermal plants) for electricity is a possibility for East Africa, only preliminary research has been conducted. The region is looking at experiences in Brazil, India, and the Philippines for direction.

## **Suggestions for Further Research**

Research is needed to

- Improve the supply of fuelwood by developing efficient ways of managing trees for small-scale fuelwood supply on farms, in forests, and on woodlots; agroforestry systems with improved information on the impact of trees on agriculture and other land use; tree species suitable for multiple uses on farms (food, energy, and income); and large-scale woodfuel plantations and improved tree species and management techniques,
- Improve the supply of logging and mill residues and of agricultural waste by the use of charcoalization, briquetting, and densification,
- Improve the secondary and end-use conversion of woodfuel by modifying traditional earth kilns, designing brick kilns from traditional materials, mass-producing improved charcoal stoves, designing portable fuelwood stoves, improving (or seeking substitution of) industrial uses of fuelwood, standardizing tests and research techniques for efficiency, and designing efficient cooking utensils and encouraging cooking habits that conserve fuel, and
- Improve policy, planning, and research capabilities in the region by studying potential supplies of fuelwood, domestic consumption patterns, and deforestation issues and establishing a clearing house for research information to coordinate and disseminate findings.

## Volume 12

# Energy in Asia

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*Volume editor: Mohan Munasinghe*

# **Asia's Adjustments to the Changing Energy Picture**

*Corazon Morales Siddayao*

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## **Overview**

This paper analyzes the effects that the oil shocks of the 1970s and the subsequent policy responses had on the economies of oil-importing developing countries (OIDCs) in Asia. The OIDCs examined include Bangladesh, India, Pakistan, and Sri Lanka (all classified as low-income developing countries by the World Bank) and the Philippines, Singapore, South Korea, and Thailand (all classified as middle-income). Emphasis is given to the use of oil and other "commercial" (nontraditional and nonalternative) energy forms. Recommendations are made for further research based on the resource endowments and economic strategies of individual countries.

## **Analysis**

### **Oil Dependence and Its Implications**

For countries in the early stages of industrialization, there is a positive correlation between growth in the manufacturing sector and commercial energy demand, and the use of traditional fuels declines. In Bangladesh, the least industrialized country surveyed, the consumption of traditional fuels decreased by 25% from 1970 to 1980, whereas per capita consumption of commercial energy rose by 5.5%

from 1973 to 1981. There was also an overall increase in per capita use of commercial energy per unit of output from 1960 to 1982. From 1960 to 1981, manufacturing output generally grew faster than GDP in the OIDs analyzed. As well, per capita growth rates for commercial energy consumption generally exceeded the per capita growth rates of GDP from 1973 to 1982. These statistics suggest that increases in oil prices did not have adverse effects on the OIDs; however, the increases were largely financed by external debt. About 60–70% of the commercial energy was used for modernization (production and transportation). Oil accounted for 90–100% of the primary commercial energy consumed in the OIDs.

**Impacts on External Accounts** — The OIDs had to make adjustments to cope with the increased costs of oil and to pursue modernization. After 1972, their deficits increased dramatically because of deterioration in terms of trade, economic slowdown in the developed world, increased interest rates, and inadequate adjustments to rising energy costs. For example, from 1978 to 1981, India's surplus of 212 million USD in current accounts was transformed into a deficit of over 3 billion USD (a deficit growth of 90% annually).

From 1972 to 1978, bills for oil imports grew by 15–54% per year and continued to grow in the succeeding 4 years. Costs for fuel imports increased sharply between 1973 and 1977, and capital imports remained high. To maintain absolute levels for food and raw materials, adjustments were necessary in either the capital or foreign-aid accounts. External debt grew significantly from 1978 to 1982. Middle-income countries obtained most of their loans from private creditors; low-income countries obtained their loans from international funding agencies.

## **Policy Adjustments**

Initially, most countries assumed that energy demand was price-inelastic and responded to the first oil shock by introducing policies to dampen the impact on income, employment, and inflation. Domestic oil prices, which were held as low as possible, at times failed to reflect the economic costs of supply. In the early 1980s, however,

countries sought to manage the use and supply of energy and recognized that price plays an important role in this management.

There is a proven link between national output and energy use. However, pooled time-series data for the Asian OIDs suggest that some adjustments in energy consumption have taken place and that measures to conserve energy have often not constrained output.

Regression analyses (to evaluate the links between oil imports, borrowing, and industrialization) led to the following conclusions for the Asian OIDs:

- Manufacturing output explained most of the capital formation.
- Capital formation was affected negatively by the current account balance (of which capital imports are an important component).
- Oil imports were positively correlated with capital formation.
- Higher international prices do not seem to negatively affect investment (correlation of the relative values of oil imports and domestic investments also reflects a complementarity between industrialization and energy use).
- External debt was largely explained by oil and capital imports (oil imports were more important in the middle-income OIDs and capital imports more important in low-income OIDs).

Although the industrial sector continued to grow despite rising oil prices, this growth was supported by heavy borrowing. In Asian OIDs, capital formation and manufacturing growth generally slackened in the 1970s, and most countries in South Asia had decreased rates of economic growth. In 1980, the incremental capital-output ratio deteriorated in many of the countries because of underutilization of capacity and changes in the demand-supply structure caused by the oil shocks.

**Trade and Related Adjustments** — An important adjustment to the oil shocks was to diversify export earnings by increasing production of manufactured goods, especially in East Asia. Singapore and South Korea, which followed export-oriented policies after

the first oil shock, experienced high rates of economic growth and only slight increases in their incremental capital–output ratios. In contrast, OIDs that pursued policies of import substitution after the first oil shock doubled their incremental capital–output ratios.

**Energy, Employment, and Income** — Because of inflexible levels of complementarity of energy, capital, and labour, a reduction in energy use results in capital underuse and increased unemployment in the short run. Estimates of the elasticity of substitution among these inputs over a longer period have focused on the developed world and have yielded mixed results. The elasticities of substitution between labour and energy and capital and energy in several Thai industries are generally high. The impact that a reduction in energy use has on employment is not sufficiently understood and requires more research.

**Managed Retrenchment in Energy Use** — Energy conservation can be either voluntary (effected by prices, taxes, and subsidies) or involuntary (mandated). In the OIDs studied, pricing was the most important policy introduced to affect energy demand. Policymakers discovered in the second half of the 1970s that policies that were designed to keep prices down were creating severe misallocations. Price changes were erratic in relation to, and generally lower than, international prices. Energy pricing has been linked to social goals of development (for example, the redistribution of income). However, these policies often result in inefficient use of energy and in delays in adjustment to energy conservation programs. Although pricing may explain some of the reductions in energy use that occurred in the Asian OIDs, the use of more efficient equipment also contributed. The costs of other inputs also influenced the proportions of energy costs.

**Policies that Influence Supply** — On the supply side, the response to the oil shocks was to diversify the supply base. This was characterized by increased involvement of the public sector in the development of indigenous petroleum resources. Policies were also



adopted to increase the use of other energy sources (for example, coal, geothermal, hydroelectric, and renewable resources).

## **Realities and Policy Implications**

Modernization and energy consumption are intrinsically linked. Oil will remain the dominant commercial energy source throughout the next decade. As most developing countries seek to achieve their development goals, financial barriers may constrain their access to oil.

Energy conservation is the most important approach to the management of energy demand. Conservation involves both engineering and economic considerations and can be achieved by process and system modifications or by the restructuring of production inputs. Pricing policies have a great influence on energy conservation and involve value judgments about what constitutes “optimal” welfare. As a minimum, pricing policies should cover the economic costs of supply.

As countries attempt to diversify their supply base, natural gas and coal are viewed as important substitutes for oil. Alternative fuels are also being examined, but there are a number of problems associated with their use. Despite declining oil prices, the cost of oil for OIDs remains high. Therefore, the market share of petroleum substitutes is expected to increase gradually. Asian OIDs must reconsider their productivity targets for the mix of energy and technology if they are to achieve both their socioeconomic goals for modernization and their efficiency goals for energy and labour.

## **Suggestions for Further Research**

There is a need for further research to understand

- The reasons for differences in energy efficiencies among industries, sectors, and countries (for example, in technology, management of production, and industrial structure),
- The extent to which conservation is possible (and its cost),
- The possibilities of transferring the analytic methods,

- The data required to do useful policy-related research and planning and the ways the data may be obtained, and
- The role of the public sector in the planning and implementation of policy using the tools available to them.

# **Korea's Energy Solution: Maintain Economic Growth and Manage Energy Supply and Demand**

*Ho Tak Kim*

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## **Overview**

This paper examines the changes in the energy sector in the Republic of Korea from 1965 to 1983 and focuses on responses and adjustments since the first oil shock (in 1973–1974). Korea experienced phenomenal export-led growth in an economy weak in energy resources. The supply and demand of energy resources in Korea are surveyed in relation to the oil price increases of the 1970s. These higher oil prices also had an adverse impact on the balance of payments. The government's policy on energy pricing, incentive policies, and regulatory measures are described. The paper concludes that governments must approach energy issues in an integrated manner. Management of energy demand is recognized as a key to an energy-efficient economy.

## **Analysis**

From 1965 to 1983, Korea experienced remarkable growth (gross domestic product (GDP)) increased at an average annual rate of 8.8%). Manufacturing increased its contribution to GDP, and heavy and chemical products became more important than light industry.

Exports increased by 125 times during 1965–1982 and greatly increased their contribution to GNP. Inflation was high, particularly after the oil shocks, and soared over 20%. Growth of the economy by means of an export-led strategy was the main goal of the government until 1978. In the 1970s, labour-intensive and capital-saving industry began to give way to heavy, energy-intensive industry, which the government continued to promote even after the first oil shock. Because of concern about economic overheating, a policy of stabilization was adopted in 1978 to control growth in GNP and inflation.

### **Energy Resources: Supply and Demand**

Korea lacks natural energy resources. It has a small coal supply and limited hydroelectric potential. Nonetheless, energy demand quadrupled from 1965 to 1983. Dependence on imported energy increased from 13% in 1965 to 75% in 1982. Demand sharply decreased for traditional energy sources and sharply increased for petroleum products. These changes in demand were caused by growth and structural change in the economy and by changes in lifestyle and government policy. Increases in the price of oil temporarily slowed growth in energy demand but did not decrease demand.

The substitution of oil for other forms of energy proceeded rapidly until the first oil shock. After this, growth in oil demand decreased by half; however, oil demand continued to outpace total energy demand from 1975 to 1979. The second oil shock had a greater impact. There was an absolute drop in the consumption of oil and slower growth in total energy demand. Future demand for energy will depend on growth and structural changes in the economy, changes in energy prices and technology, and government policy. Dependence on fuel imports is likely to increase to 90% by 2001, and total energy demand will triple. Because of increasing reliance on coal and nuclear power, dependence on oil should decrease to 30%. The industrial sector will continue to be the largest consumer of energy. From 1965 to 1982, energy intensity decreased slightly (but

less than in the industrialized world) because of increases in oil prices and energy-saving policy measures.

**Oil Price: Effects on Demand and the Economy** — Relative oil prices do not directly determine the demand for fuels, but they influence government policy. Government policies have emphasized economic growth, and Korea has used energy policy to support this goal. In response to increases in oil prices, the government took steps to increase the use of domestic resources and to diversify fuel sources. As a result, oil dependency declined after 1979.

Oil shocks, however, had a number of negative impacts on the economy (for example, inflation, balance of trade, balance of payments, external debt, and terms of trade). Increases in oil prices were responsible for over half of the 42% increase in the wholesale price index in 1974. In 1974, the oil bill accounted for almost 60% of the increase in the trade deficit. The increase in the import bill in 1979–1980 was solely due to an increase in the oil bill. After the first oil shock, Korea overcame its foreign exchange crisis by borrowing from abroad and earning oil dollars from increased exports to the Middle East. The second shock was more damaging to the balance of payments because it was financed by an increase in external debt. The country's terms of trade also deteriorated in 1974. The first oil shock did not have a significant effect on GDP, but it is difficult to estimate the effects of the second shock because a number of other variables also influenced GDP.

Increases in oil prices had a much more important effect on manufacturing than on agriculture (where the effect was marginal). Because of its large share of oil consumption, the manufacturing sector was hard hit by the oil shocks, particularly the second one. In 1980, manufacturing experienced negative growth; this was followed by slow growth in 1981–1982. As a result, manufacturing made major adjustments in energy conservation, interfuel substitution, and production prices.

## Energy Demand by Sector

Although the direct energy input into agriculture is insignificant, a number of changes may increase the demand for commercial energy:

- Subsistence farming is becoming more commercialized, and this is increasing the demand for chemical fertilizers and mechanized farming equipment.
- Irrigation and water pumping are now mechanized.
- Artificial heating is being used in greenhouses to produce vegetables during the off-season.

The manufacturing sector is the largest consumer of energy in the economy. In 1982, it consumed 62% of the electricity and 31% of the oil. Over two decades, the fuel mix changed as the share of coal decreased and petroleum products and electricity increased. Energy consumption in the transportation sector grew even faster than in the manufacturing sector. The share of transportation in overall energy consumption increased from 5.6% in 1965 to 15.1% in 1982. In the 1960s, the residential and commercial sectors were the largest consumers of energy (60%), but their share had fallen to 36% by 1982 and commercial fuel was replacing traditional energy sources. In addition, electrical transformation losses have increased because of expanded use of power.

## Policy Reactions and Policy Formulation

The sharp oil price rise in 1974 led the government to develop an energy policy that restricted oil consumption, encouraged production and consumption of domestic energy sources (for example, coal), and changed the mix of imported fuels. After the first shock, the most urgent goal was to secure oil supplies and to minimize disruption in the economy. Since the second oil shock, government policy has attempted to restructure industry to become less energy and technology intensive.

Although energy demand management (EDM) has been a priority in economic development plans since 1973, related programs and policies have not been successful. After the first shock, no subsidies were provided for investments in projects to conserve energy. The

government tried to achieve EDM goals by using administrative power and mandatory measures.

## **Pricing Policy**

Pricing policy is a key element in EDM. Before the oil shocks, pricing policies were used to promote industrial development and to subsidize the poor. After the first oil shock, the government adopted the principle of marginal-cost pricing for petroleum products. This principle has not been adopted as quickly for the coal and electricity sectors. As a result, industry has been subsidized by the domestic and commercial sectors. In pricing policy, the government has generally emphasized growth, inflation reduction, and welfare rather than energy conservation. Generally, the government sets a national ceiling price for each fuel and then uses taxes and subsidies to harmonize the interests of consumers and producers. The government has used value-added taxation to influence or induce substitution. Before the first oil shock, a preference for oil consumption was clear. This was reversed after 1973. Imposed price differentials, particularly between coal and oil, have induced fuel substitution. In the oil sector, a high tax premium was placed on gasoline, whereas no premium was placed on domestic and industrial fuels (for example, diesel, kerosene, and naphtha).

Increases in energy prices after the oil shocks changed the short-run demand for petroleum products. If energy prices had not increased, energy demand would have increased faster than actual growth. Current economic models do not adequately explain the effects observed after the two shocks. Because energy prices changed at different rates and led to substitution among fuel sources, effects of price changes should be examined for different sources rather than for aggregate demand.

Despite this lack of economic knowledge, conclusions can be drawn about the shortcomings of Korean domestic policies. Pricing was used to promote fuel substitution, not conservation. Energy efficiency was impeded: manufacturers could easily pass on price increases to consumers because domestic markets were protected from foreign competition.

## **Incentive Policies and Programs, Regulatory Measures, and Education Programs**

Until 1980, the government used regulatory measures rather than incentives (subsidies, taxes, and concessions) to promote energy efficiency. Since 1981, the government has offered conservation incentives to the industrial sector, but these have not been enough to motivate major investments.

After both oil shocks, the government imposed a series of short-term regulatory measures in the transportation, commercial, and public sectors. As well, the Energy Rationalization Law was enacted to induce energy conservation and fuel substitution in the industrial sector. Although it is difficult to measure the specific success of each measure, their combined effects are substantial.

In addition, numerous education, training, and information programs are provided for EDM in Korea. The media promote conservation, and the government and private sector sponsor informal public lectures and instruction. Students are instructed in the basic concepts of energy conservation, and adults receive more advanced training in energy management.

The government also conducts audits of plants that are considered "designated heat users." Auditors estimate that energy consumption could be cut significantly by conservation measures. The promotion of fuel substitution has been successful in the cement industry but slow in other industries. This delay results because the incentive programs are voluntary and lack fiscal incentives. Because the electricity sector consumes 20% of total energy and its share is increasing, programs to promote energy conservation and fuel-switching in this sector are necessary. The government has also been promoting the use of cogenerated power, which can result in substantial energy savings for industry.

The various EDM programs have been supported by appropriate changes in the organizational, institutional, and legal framework. Energy issues must be approached in an integrated fashion to enhance the effectiveness of individual programs.



### **Suggestions for Further Research**

Further research is required to understand the behaviour and responses of energy consumers to changes in policies. More research is also needed to improve the methods used to evaluate the effectiveness of EDM policies.

# **India's Energy: Problems and Solutions for Research Programs**

*Bharat Bhushan*

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## **Overview**

This paper analyzes the R&D program for energy in India. It presents the broad patterns of energy use in different sectors of the economy and outlines the importance of different sources of energy in various consuming sectors. Technological and economic problems and potential directions for technical change are identified. The effectiveness of the R&D program for energy in India is evaluated in this context. The R&D programs of several research institutions are examined, their effectiveness is evaluated, and recommendations are made to improve the efficacy of the R&D system.

## **Analysis**

### **Patterns and Problems of Energy Use**

The share of coal in total commercial energy fell from 79.3% to 74.7% between 1960–1961 and 1975–1976, whereas the share of electricity rose from 7.2% to 15.5%. The largest consumer of commercial energy in India is the industrial sector (38.5%), where coal dominates. Over the same period, the share of electricity rose while the share of oil declined drastically. The next largest consumer of commercial energy (mostly oil) is the transportation sector. There has been an absolute decline in coal consumption for transportation

because of shifts in rail technology. This decline has been accompanied by an increase in the consumption of oil. The share of electricity has remained unchanged. Households are the third largest consumers of commercial energy, although because of reliance on noncommercial forms, this sector accounts for nearly half of the total energy consumed in India. Agriculture accounts for 10.6% of the use of commercial energy. The consumption of oil increased 15-fold and the consumption of electricity increased 7-fold between 1960–1961 and 1978–1979. A notable trend is the slow, but perceptible, commercialization of noncommercial fuels.

Across all sectors, there are inefficient uses of energy. For example, in the industrial sector, the use of electricity could be reduced by the proper selection of motors and by improvements to electrolytic processes and lighting. In the transportation sector, the rapid growth of road transportation and the slow phase-out of steam locomotives are major contributors to the inefficient use of energy. In the agricultural sector, more efficient pumps and tractors and increased numbers of draught animals could improve energy efficiency. Attempts could be made in the household sector to reduce the consumption of liquefied petroleum gas and kerosene in domestic appliances. The use of noncommercial energy (for example, firewood, biogas, and solar) could also be promoted.

## **Technical Problems in Energy Production**

The three categories of technical and economic problems in energy production are increasing current production, locating new areas of production, and transporting or transmitting energy.

To increase coal production the methods of mining must be changed. Since the mid-1970s there has been a move away from the traditional stope-and-pillar method (which recovers only half the coal in place) toward methods that recover all of the coal from deep mines. Opencast mining is another way to remove all of the coal. The two problems related to the transportation of coal (which takes place mainly by rail) are theft and inefficiencies in the loading and unloading of wagons.

Oil production from existing sources could be increased by enhancing oil recovery from developed wells, deep drilling, and using secondary processes for refining. The product mix and investment must be considered when choosing between catalytic cracking or hydrocracking for secondary processing. If the production of oil is to be increased by expanding the resource base, efforts must be focused on

- Fields that are already discovered but are not prepared for commercial exploitation,
- Areas where geological prospecting indicates that oil exists but has not yet been discovered, and
- Areas where geologic anomalies indicate that sediments will produce hydrocarbons although technology can provide no concrete information on these basins.

The problem with transportation of oil is the choice between rail and pipelines. Gas is more difficult to exploit and transport, and therefore its production is only economic if discoveries are large (for example, offshore resources).

The three problems related to the production of thermoelectric power are the lack of adequate spinning reserves and a high probability of disruption in the power supply if the generators fail, fluctuations in the quality of the coal, and the transportation and handling of the coal.

Nearly 40% of hydroelectric power potential is located in the northeast frontier, where large-scale generation and transmission are not feasible. The three primary problems with nuclear power are weakness in designing power reactors, crucial weaknesses in the heavy-water program, and difficulties in the fast-breeder program. To increase the generation capacity of India, its remaining hydroelectric potential, which is estimated to be 80% of total useable hydroelectric resources, must be unlocked. High-voltage transmission is not yet in commercial use for the bulk transfer of power, despite its potential to reduce losses.

Animal power, solar energy, wind energy, and biomass are important noncommercial forms of energy. The major deficiencies for solar energy are the design of the collectors and the capability to

produce the raw material for photovoltaics. Windmill designs must be adapted to local conditions and to locally available materials. Biomass can be used for direct combustion, producer-gas generation, and biogas production. Severe shortages of standing biomass must be overcome by research into species that grow rapidly and are adapted to dry tropical conditions.

## **Potential Directions for Technical Change**

Coal production could be increased by using longwall mining and powered support faces. Schemes to extend mechanized depillaring might also increase production. Rapid systems that load coal into wagons while they are still in motion are being considered.

The possibilities for technical change in the production of oil lie in the use of nonthermal enhanced oil recovery (EOR) methods (for example, the flooding of wells with water or polymers). Hydrocracking units should be investigated for secondary processing, and better drilling techniques must be developed for deep wells. Computerized processing may help to improve the identification of potential sites.

The government is encouraging the establishment of super-thermal power stations at the mouth of coal mines. The development of generators and turbines that could perform efficiently at low loads would improve electricity generation from mini- and micro-hydroelectric projects. Three areas that require technical change in nuclear power generation are mastery of the design and function of existing reactors, development of capabilities in the production of heavy water, and solutions to problems associated with carbide fuel. High-voltage direct current transmission should also be commercialized.

The most significant change in noncommercial forms of energy is the production of polycrystalline and single-crystal silicon for photovoltaic cells. Experimental wind farms have been established, and emphasis should be placed on the development of the skills required to use wind generators.

## **Effectiveness of R&D Programs for Energy**

Government expenditures on energy R&D (excluding electricity) are about 28 million USD. In addition, a host of private and nongovernmental organizations (NGOs) carry on separate research activities. These efforts do not appear to be coordinated. The petroleum sector receives the largest amount of resources, followed by nonconventional energy and coal. The R&D system for energy has sufficient human resources and physical infrastructure. However, it has not achieved self-sustained, effective development of energy systems because of inadequate administrative and technical planning. The effectiveness of R&D programs for energy should be evaluated according to their ability to solve production problems.

The Central Mining Research Station (CMRS) has done some work to intensify coal production. In addition, it has designed props and reversible steel-link bars. Its work on strata control in stope-and-pillar and longwall mining has been good, but this work has been rendered ineffective because CMRS is not involved in the selection of longwall technology. The intensification of coal production is likely to take place on a case-by-case basis. In the case of coal exploration, the program of the Central Fuel Research Institute (CFRI) for the assessment of resource quality has been reasonably successful, but most discoveries have been of noncoking coal. Loading innovations developed at Coal India Limited may improve coal handling, and CFRI is studying pipeline transportation. The work by CFRI on coal preparation may help to offset the shortage of prime coking coal. However, CFRI, which is the nation's premier research institution on coal use, has produced few worthwhile results and may require better monitoring.

Four research agencies conduct most of the research to intensify oil production. Most research programs are in the preliminary stages. EOR schemes are an exception. Schemes developed by the Institute of Reservoir Studies (IRS) have been used with some success in a number of fields. Research on deep-well drilling remains weak. The Indian Institute of Petroleum (IIP) has conducted useful research on

hydrocracking and oil transportation. Research by IIP on alternative fuels is still at the testing stage.

More than a dozen private and public agencies are active in R&D in electricity. Bharat Heavy Electricals Limited (BHEL) has designed 200- and 500-MW generators. A number of agencies have designed and developed micro- and mini-hydroelectric plants. Three agencies are involved in research programs on nuclear generation. Experiments are being done on breeder reactors, and designs are being developed for heavy-water plants, uranium enrichment, and other aspects of the enriched-fuel cycle. On the whole, R&D in nuclear power has not been effective. Several institutes run research programs for transmission and distribution. Extra-high voltage transmission and related equipment is a focus for BHEL.

Success is more difficult to gauge in R&D on noncommercial energy sources because the applications are small and decentralized. Some success has been achieved in the production of new processes and techniques for flat-plate collectors and in single-crystal and polycrystalline photovoltaic cells. Mismatches between R&D and the needs of consumers are evident in the areas of solar conversion to heat, solar cookers, and solar refrigeration. R&D on biomass production is still at the stage of screening and evaluating fast-growing fuelwood species. Research in animal power has been ineffective. Research on wind energy has resulted in the commercialization of several small pumps that have experienced technical difficulties.

## **Improving the Efficacy of the R&D System**

There is no point to improving R&D on energy unless energy research is subordinated to democratic social and political goals. Institutions must also be made accountable for the efficacy of their work. The effectiveness of the R&D system could be enhanced if

- Broad policies were developed to emphasize energy conservation and the efficient use of energy (these policies would help focus research on the industrial, agricultural, and transportation sectors),

- Centralized planning, monitoring, and coordination were improved, and
- Technical planning was improved to eliminate mismatches between R&D and the real needs of users, poorly timed imports of technology, and the lack of the skills and infrastructure necessary to assimilate technology and imports.

Specific steps could be taken to improve R&D on each fuel type. For example, R&D on coal would be more effective if production plans involved the CFRI from the beginning. R&D programs on coal use should be reviewed regularly and should be conducted in cooperation with industry. The efficacy of R&D to develop oil production could be enhanced by an assessment of the need for technology imports. There should also be an integrated national program on fuel-efficient engines and the testing of alternative fuels. R&D on electricity could be improved if investment in thermal, hydroelectric, and nuclear generation were based on the projected contributions of each source. Nuclear power must be evaluated by independent auditors. To improve the effectiveness of R&D on noncommercial forms of energy, the case-by-case sanctioning of projects must end. Large research projects must be tendered and monitored, and equipment and designs should be standardized.





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**Energy in China**

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*Volume editor: Zhu Yajie*

# **Demand, Supply, and Economics of Energy in China**

*Zhu Yajie et al.*<sup>1</sup>

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## **Overview**

This paper documents current energy consumption in China. Supply is described with reference to issues of distribution, production, transportation, and environment. The economic effects of pricing policies are discussed. Suggestions are made on ways to improve output from industry and agriculture by using pricing policies and related improvements in efficiency.

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<sup>1</sup> This paper was compiled from 13 papers commissioned by the Energy Research Group: *Rural Energy Utilization in China* by Deng Keyun and Wu Changlun; *Recent Advances in Solar Energy Utilization in China* by Gong Bao, Lu Weide, and Tian Ziaoping; *China's Energy Economy* by Lan Tianfang, Lu Yingzhong, and Mao Yushi; *Industrial Energy Consumption and Conservation in China* by Lu Qi and Lu Xueyi; *The Development of Electric Power in China* by Lu Qinkan and Fu Zhesun; *The Development of Nuclear Energy in China* by Lu Yingzhong; *China's Transport and Energy Use* by Mao Yushi and Hu Guangrong; *Petroleum Industry in China* by Qin Tongluo; *Geothermal Energy in China* by Ren Xiang, Yang Qilong, and Tang Ninghua; *The Coal Industry in China* by Wu Jing; *Biomass Utilization in China* by Wu Wen; *Energy Policy Study in China* by Zhu Yajie and Wang Qingyi; and *How Small Hydro Power is Helping China's Rural Electrification Program* by Zhu Xiaozhang, Ding Guangquan, and Eugene Chang.

## Analysis

Although China's annual growth in energy production has averaged 10% since 1949, consumption has outstripped growth in GNP. In 1979, the government announced its goal to quadruple industrial and agricultural output by the year 2000. Both sectors have been constrained by an energy shortage caused by inadequate and inefficient technology in the transportation and transformation sectors.

### Current Consumption

**Domestic** — Noncommercial energy sources (crop stalks, firewood, and animal and human wastes) supply 85% of the domestic energy used by rural residents (85% of China's population). About 10% of the electricity produced in China is consumed for domestic uses, less than half of it in rural areas.

**Agriculture** — In the agricultural sector, people and animals are still the major source of energy, and this inhibits increases in productivity. Chemical fertilizers consume 42–86% of the commercial energy used in the sector. Irrigation and drainage consume almost one-third of the electricity supplied to rural areas, but the power is inadequate. Yields per unit of commercial energy input are low.

**Industry** — The industrial sector, primarily heavy industry (chemical, iron, and steel), consumes 75% of the electricity and 51% of the oil produced in China. Although the contribution of hydroelectricity is growing, the power industry is primarily fuelled by coal. Generation efficiency is low, and transmission losses are high.

**Transportation** — The transportation sector represents 7% of total energy consumption. Railways account for a high share of traffic. Although electric locomotives have been introduced in China, most locomotives are steam-powered, coal-fuelled, and relatively inefficient. The fleet of diesel trucks is outdated.

**Exports** — China has exported coal, coke, oil, and uranium since the early 1950s. In the short term, these exports are expected to

continue, and the export of coal is expected to increase. In the long term, the proportion of oil exports is expected to diminish.

## **Production and Use of Energy Resources**

Although China is rich in energy resources, they are unevenly distributed throughout the country. The provinces south of the Yangtze River account for 13% of the total per capita energy resources and 65% of the consumption. Biomass is the major supplier of energy.

**Coal** — Coal is the key source of commercial energy in China and accounts for 70% of energy supply. China's coal reserves are primarily located in the north, far from the major centres. Joint ventures with foreign companies are planned to develop five large mines and to test new mining methods, equipment, and management techniques. Transportation is a significant problem; therefore, pumping of coal slurry by pipeline is being explored, railways are under construction, and three of the mines will have on-site power stations.

**Oil and Gas** — Oil and gas account for one-quarter of the primary energy. The ratio of oil to gas production is high, which suggests that some gas reserves may have been missed. Exploration is underdeveloped, and agreements have been signed to acquire technical expertise and offshore exploration from foreign companies. Research is being conducted to improve recovery efficiencies. Increased production of petrochemicals, primarily nitrogenous fertilizers, is planned.

**Hydroelectricity** — Only 4% of exploitable water resources are being used to generate electricity. At least 10 stations with installed capacities greater than 1.0 GW will be constructed. Local communities are given subsidies for small hydroelectric projects. Problems include high resettlement costs, silting, and uneven supply because of seasonal runoff.

**Biomass** — Biomass is the major source of energy in rural areas. Firewood has been harvested at twice the recommended rate. The majority of stoves used in rural households have an efficiency of only 10%, although design improvements have been made recently.

Sawdust-rice husk gasifiers have been developed. Many of the biogas digesters built before 1979 are unused because of poor design or improper maintenance. Ethanol is produced by fermentation, but only one-third of the potential output is achieved because of high production costs.

**Geothermal** — Although little of China's geothermal capacity is currently used, up to 2% of total energy consumption could be met by the year 2000. Geothermal water is being used to produce electricity in seven power stations. There are few industrial applications; geothermal fields have been used mainly for public baths. The main problems are scaling and corrosion of wells and equipment.

**Solar** — Although there is considerable potential to use solar energy, it is currently meeting less than 1% of demand. Research on solar materials and photochemistry is focusing on low-temperature applications that use flat-plate collectors and different coatings. Solar water heaters and cookers are commercially available, and hot water is supplied for public facilities (for example, barber shops, bathhouses, hotels, and hospitals). Solar water heaters have a short life span, are subject to corrosion and other damage, and are not yet mass-produced.

**Nuclear** — In the next 20 years, proponents expect that nuclear generators will produce 7% of the commercial energy. The pressurized water reactor is considered the most suitable reactor. However, given the current subsidies for coal, nuclear power stations are only economically feasible under certain conditions. Research on the use of nuclear energy for home heating, as process heat for industry, and for the production of liquid fuels is ongoing.

**Other** — There is some potential to use wind energy for irrigation and to produce electricity. A number of small tidal power plants have been built for irrigation and to fuel local industries, but their potential to generate electricity is low.

## **Environmental Effects**

The two most significant environmental effects of the consumption and production of energy in China are air pollution (from burning coal) and soil degradation and erosion (from burning biomass). The concentrations of particulates and sulfur dioxide in most cities and industrial centres exceed allowable health limits, and acid rain is a serious problem in southwest China. Although some remedial measures have been introduced (for example, substitution of gas, use of low-sulfur coal, coal liquefaction with sulfur removal, and adoption of fluidized-bed technology), the problem is likely to worsen in the short term as coal is substituted for oil.

Illegal harvesting of firewood has contributed to soil erosion, desertification, deterioration of the climate, and ecological imbalance. The harvest of trees and crop residues for fuel results in the annual loss of 5 Gt of fertile soil. The loss of nitrogen corresponds to the total production of chemical fertilizer. The government has started to promote afforestation and grass planting, fuel-saving stoves and biogas digesters, small hydroelectric power stations, and small coal mines.

## **Conservation**

Waste and inefficiency in energy use are attributed to the predominance of small-scale enterprises, the poor quality of feedstocks and fuels, irrational siting for industries, obsolete equipment, low thermal efficiency in industry, and low prices for energy, particularly coal. Energy intensities have been improved since 1979 because of a number of government measures. These include the closing, merging, and transferring of small enterprises, a move away from energy-intensive heavy industry, the introduction of standards and economic incentives for energy management, an emphasis on the capture of waste heat in production processes, the use of mine wastes in fluidized beds as a replacement for raw coal, the capture of methane gas from coal mines, and the use of advanced energy-saving technologies in the iron and steel industry.

## **Economics**

For the past 35 years, the government has controlled energy prices. The prices for coal and oil are significantly below international market prices, and demand exceeds supply. In the past, the average price of coal was well below the average cost; therefore, half the mines were run at a loss. Because the price of oil is higher than the average cost of production, the government earns an annual profit. Electricity produces a high rate of return, but rational use should be encouraged by differential pricing. Given the current shortages and the high return on investment, there is underinvestment in electrical power generation.

Low energy prices have encouraged the development of heavy industry and waste. Energy-intensive products are exported at prices much below their true cost. The government has introduced a two-tiered price system. The controlled price is paid for rationed amounts, whereas market price is paid for additional energy. This price system has been introduced with no perceptible increase in inflation.

## **Conclusions**

No model provides an accurate forecast of future demand given the new targets and the uneven distribution of resources and consumers. To increase output in the agricultural sector, the proportion of energy going to rural areas must be increased significantly. The policy on rural energy formulated in 1980 introduced such measures as firewood-saving stoves, afforestation for fuelwood, development of biogas digesters, and construction of small hydroelectric stations, small coal mines, and alternative energy projects.

Conservation is a key to increasing both industrial output and electricity supply. Pricing strategies and other economic incentives are powerful tools that should be used to promote energy savings and to increase efficiency.



# **Economic Reform: Effects on Energy**

*Mao Yushi*

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## **Overview**

This paper describes China's energy economy in the context of its natural resources, history, and political, macroeconomic, and microeconomic characteristics. The implications of recent economic reforms are discussed. Measures for price reforms are recommended, and strategies for their gradual introduction are advanced.

## **Analysis**

China's energy economy is unique because it relies on coal for more than 70% of its commercial energy, its energy intensity is high, the percentage of energy used by households and for transportation is low, a large proportion of oil is consumed by direct burning, and diesel oil is used more than gasoline.

## **Natural Conditions**

China's geography makes transportation difficult. Energy resources and population are distributed unevenly. Precipitation varies markedly by region and season, and much of the excess rainwater is wasted. Extremes in temperature necessitate increased consumption of household energy to improve the standard of living.

The country's coal reserves are believed to be the largest in the world. Much of the coal has less than 1 % sulfur and is easy to exploit. However, the distribution of these reserves does not correspond to population density, and the fuel must be moved long distances by rail. China does not required removal of sulfur dioxide from smoke, which has caused air pollution problems in densely populated areas.

Estimates of China's recoverable oil reserves range from 5.5 to 15 Gt. Based on the fields that are currently producing, the production target set for the year 2000 will not be reached unless large new reserves are found.

Natural gas provides only 2% of the primary energy. It is not readily marketable because the pipeline system and downstream industries are underdeveloped. China does not have a liquefaction factory.

There is abundant solar energy, but many technical and economic problems must be overcome before it can be used. Therefore, the contribution of solar energy, as well as wind, geothermal, and tidal energy, will be negligible in the next decade.

## **Historical Development**

When the People's Republic of China (PRC) was founded in 1949, per capita income and energy production were low. The First Five Year Plan in 1953 rapidly increased per capita income. In general, the industrial sector has been successful since the founding of the PRC, and the increase in energy output has exceeded the increase in national income. Agriculture accounts for 68% of the national income. Transportation is scarce, and peasants traditionally use biomass energy. Rural demand for commercial energy has remained unsatisfied. Despite large reserves of water and coal, per capita energy resources are half the world average. China is a typical developing country because aging equipment contributes to low energy efficiency, there are few automobiles, there are many trucks that require diesel fuel, and there is essentially no technology to control air pollution.

## **Political and Macroeconomic Policies**

Nearly all of the peculiarities in the energy economy can be attributed to planned development. In 1956, the country began to transform from private to public ownership. Managers of state-owned enterprises assumed no responsibility for profits or losses. In the early 1960s, the defence industry consumed a disproportionate amount of energy, the government built factories in remote locations, and the development of nuclear power focused on weapons rather than on power plants. In 1978, China launched a policy readjustment. It gradually discarded the Soviet model of economic planning, which is characterized by distorted prices and poor communication, investments in heavy industry, an inadequate supply of consumer goods, a low standard of living, and inefficient use of resources. Since the start of the current economic reform, collectives have gained decision-making power, private enterprises are emerging, and market forces are being taken into account in the management of state-owned enterprises.

About half of China's coal is produced by the central government and distributed according to state planning targets. The remainder is distributed through market channels. Returns on state investments are poor. All major electrical power plants and transmission grids are owned by the state. Only since 1985 have the industrial and municipal sectors been encouraged to cooperate in power generation. All lands, forests, and minerals are owned by the state, which has often been irresponsible in their protection.

The policy on family planning has reduced net population growth to 1.15% and put pressure on the rural labour force. This will result in increased demand for commercial energy by rural families, increased mechanization in coal mines, and increased demand for specialized labour to construct hydroelectric power stations and develop the oil industry.

A range of problems plague the production system. China has a high ratio of capital goods to consumer goods, and a high level of intermediate energy goes into capital goods. Investment in production is unpredictable, and return on investment is disregarded.

Planned allocation results in a lack of coordination and sharing of activities between enterprises. Many energy-producing regions are underdeveloped compared with energy-consuming regions, and this gap is increasing because energy prices are too low. A recent tax reform has narrowed the gap, but the problem will not be solved unless the whole price system is readjusted.

The Soviet model of development favoured the industrial sector and ignored the agricultural sector. This resulted in inequity between urban and rural households. Little of the energy for planned distribution flows to rural areas, and less than half of this energy is available to households. Environmental damage results because of excessive felling of trees, and subsequent soil erosion and nitrogen loss lead to rural poverty. Since 1984, the government has supplied more coal to the poorest rural areas in exchange for labour to plant trees and grass. Since 1979, numerous small coal mines have been developed. This has helped to alleviate ecological deterioration and has used surplus labour and capital. However, these mines have low recovery rates and poor working conditions.

### **Microeconomic Aspects**

Most Chinese energy experts, and some foreign experts, believe that China has a serious shortage of energy. Chinese authorities have declared that energy and transportation shortages are the major obstacles to economic development.

However, it appears that the problem is not an energy shortage, but too low a price for energy, particularly for coal (which accounts for 70% of primary energy supply). The energy demands of rural areas have not been fully reflected in the market, and there is a real shortage of energy for rural use. To correct the distortion in supply and demand for oil, China should decrease its oil exports. There is a serious shortage of electricity because of inadequate investment. The supply-demand relationship is ignored in the pricing of electricity, and there is no differential pricing for peak use, seasonal variation, or source of power.

Rural industries require improved technology, more capital, and less regulation to improve energy efficiency. Conservation, achieved

in the past by ignoring economic cost, should be guided by market forces. The government is proceeding with legislation to promote conservation, but its efforts generally have not been effective.

Planners are uncertain about how to renovate the rail system. Diesel locomotives are thermally efficient, but future oil prices are uncertain. However, the supply of coal for the less efficient steam engine will remain stable and reliable. Small hydroelectric power plants have benefited rural residents, but in an efficient capital market, some of this capital would have been used to build larger plants that would produce more, better quality electricity.

Technological innovation has not been used to improve the efficiency of resource utilization. The potential to conserve energy by saving raw materials has not been explored. In addition, government pricing policies block the reallocation of resources, particularly in the transportation industry.

## **Reform of the Economic Structure**

Recent reforms, which have been based on the use of foreign capital and technology, the exchange of personnel and information, and more decision-making by enterprises, have had a profound influence on the economy. Unprecedented growth was experienced in agricultural output and there was more than 12% annual growth in urban areas in two consecutive years after 1984. The output of coal and oil exceeded past records, and conservation measures continued to be successful.

However, authorities in commodity distribution lack theoretical guidelines and correct price information to guide resource allocation. Price reform is a major step in economic reform, but the removal of government interference alone will not enable market prices to approach equilibrium. Managers of state-owned enterprises will be influenced by short-term interests. A dual-price system can greatly alleviate objections from vested interests. Prices have been set for coal and oil that are purchased within a quota. A floating price is established for above-quota production or consumption. A dual price for electricity is still in its initial stages.

A dual-price system should be used as a transitional measure. Economic reforms are bringing about structural changes in the economy. Competition and market forces will improve the allocation of resources. The costs will include scrapping of inefficient equipment, retraining of labour, and large investments in new sectors. Chinese producers and consumers will have to make considerable adjustments to adapt to the uncertainty of the economy, which is inevitable in an unpredictable market.

# **China's Energy: Advances and Limitations**

*Vaclav Smil*

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## **Overview**

This paper describes the supply, production, and use of China's energy resources. The energy and environmental implications of achieving the planned level of growth in the industrial and agricultural sectors are discussed. Recommendations are made on ways to expand China's energy systems to meet the challenges of a high-growth economy.

## **Analysis**

China's population is primarily rural and depends heavily on biomass. Attempts to industrialize the economy have been based on inefficient use of inadequate supplies of fossil fuels and electricity. However, the country is unique because its modernization since 1949 has been guided by a Stalinist central planning approach, its population represents 22% of the world's total, and its energy resources should allow the country to be energy self-sufficient in the long term.

## **Resources**

Although China has the world's largest potential for exploitable hydroelectric energy, huge coal reserves, and significant potential for large hydrocarbon reserves, these resources diminish in significance

when they are expressed on a per capita basis. Solar radiation is abundant but reliable only in the sparsely populated northern half of the country. Therefore, the potential for widespread use of solar energy for households is limited. Although hundreds of small wind generators and several larger units are in operation, wind power will continue to contribute negligible amounts of energy. Geothermal potential is significant, but only a few sites are suitable for power generation.

Large rivers that originate on the world's highest plateau present opportunities for the construction of huge hydroelectric stations that on some sites are suitable for projects of several gigawatts. Additional benefits of these projects would include aquaculture production and the control of river flow in a country that is prone to flooding and drought. However, these sites are separated from the major centres by great distances and rugged terrain, which present major challenges for development.

Forest resources are relatively small (12% of the total area of 980 million ha), and one-third is poorly stocked secondary growth that is unevenly distributed throughout the country. Widespread deforestation and the traditional use of wood as a household fuel should be curtailed as much as possible.

The available biomass in rural areas must be used in a rational way. Crop residues should be reserved for animal feeding and bedding, small-scale manufacturing, and traditional compost. Straws and vines should be used to produce biogas.

Although detailed accounts are unavailable, verified reserves of coal are estimated to be no less than 640 Gt. Most of the currently exploited deposits contain huge reserves of low-ash, medium-sulfur, bituminous coals with relatively high energy content. However, deposits are unevenly distributed (70% of the best and most economically extractable fuel is located in the north, far from population centres).

Although in the 1970s it was speculated that China's oil and gas reserves approached those of the Middle East, growth in oil production has been curtailed recently, and the search for offshore resources has been intensified. At least a decade of exploratory drilling is



required to ascertain the reserves of crude oil, and recent indications suggest that natural gas reserves are modest. Verified reserves of fissionable uranium are sufficient to support an installed capacity of 15 GW for three decades of full-load generation.

## Utilization

Household use accounts for 7% of modern energies. For the 80% of the population who live outside cities and towns, there is widespread and seasonal energy shortage of biomass, which is the predominant fuel. Efficiency in fuel combustion is, at most, 10%. Crop residues (of which approximately 75% are burned) can also be used as organic fertilizer, feed, fuel, and raw material for manufacturing. Nitrogen is lost in the burning, as is the opportunity to improve soil structure and protect against erosion. Approximately 60% of the fuel consumed by the rural population comes from trees and forests. Commercial logging and the clearing of forests for new grainfields are excessive. The annual extraction of forest biomass is estimated to be twice the sustainable harvest. The environmental consequences of nutrient and soil losses are severe.

Alternatives to biomass combustion have been introduced. Rapid diffusion of single-family gas digesters took place in the 1970s, but many of the digesters were abandoned because their operation and maintenance were onerous. Many small hydroelectric power stations were also built, but a large number of hastily built and inefficient stations were later abandoned because of drought, siltation, or poor engineering. Transmission losses in local rural grids run as high as 25%, and there have been chronic shortages of poles and wires. Farming remains a manual occupation, and a minimal amount of electricity is delivered to rural villages. In fact, rural communities, which represent 80% of the population, consume only 20% of the fossil fuels and electricity.

Urban households consume about 12% of total energy. Rationed coal briquettes are burned for heating in inefficient stoves. Coal gas and liquefied petroleum gas are used for cooking in the largest cities. Household use of electricity is minimal. Transportation, which accounts for 8% of total consumption, is the third largest user of

commercial energy. The overall energy efficiency of the sector is about 20%, and this would be lower if not for waterway transportation. Increased diesel-fuelled shipping and additional conversion of locomotives to electricity and diesel would improve energy efficiency.

## **Production**

Impressive quantitative advances in energy production since 1949 have been made at the expense of quality, performance, and use. In 1978, a proposal was made to quadruple the output of coal before the end of the century. The main focus was to modernize large ministry-run mines, expand the capacity for coal dressing, and open large new mines in the north. Although output increased significantly, the increase was measured in terms of raw coal, and most was produced with manual labour. Only 3% of the coal originates from modern surface mines, and although China now produces modern mining equipment, its quantity and quality are inadequate to significantly improve productivity. Transportation is inadequate for current production levels despite ongoing efforts to upgrade the rail system.

Inadequacies in Chinese technology have contributed to a concentration on oil production rather than exploration. This has placed the petroleum industry two decades behind that in the West. Revival of the oil and gas industry now depends on offshore exploratory drilling that is being conducted by foreign companies. The industry faces an inadequate distribution infrastructure and inefficient refining. Artificially low oil prices have created a rising demand for heavy oil, which has resulted in a decline in deep processing. Recently, production of natural gas has declined.

Power production is inadequate by any standard. Since 1949, annual increases in electricity output averaging 15% have been achieved by the construction of thermal and hydroelectric plants and the installation of high-voltage lines (up to 500 kV). Most of the plants are small, and they cannot be linked because of transmission inadequacy. There are about 24 small, separate networks. Fragmentation and excessive loading on these networks create an unreliable power supply and result in high transmission losses. These inadequa-

cies impede the development of large-scale hydroelectric stations. China's output of generating equipment has been low, and the industry has shifted to a greater reliance on coal rather than oil.

China's energy intensity (ratio of per capita commercial energy consumption to GNP) is extremely high. The principal cause is poor conversion efficiency. Most primary commercial energy is consumed by the industrial sectors. The metallurgical and chemical industries and power generation, all inefficient converters, are the three leading users. The iron and steel industry requires 12% of the consumption of commercial energy and is especially wasteful. However, high targets for conservation have resulted in improvements that have been achieved by better management and the installation of modern technologies.

## **Energy for the Quadrupled Economy**

China's goal is to quadruple the 1980 gross annual value of industrial and agricultural production by the year 2000. To move toward this goal, the production of coal, hydrocarbons, and electricity must be increased greatly. In addition, the country must exploit the enormous reservoir of supply that is available from conservation and improvements in efficiency. Sweeping and costly changes in the industrial infrastructure are required. Replacement of at least half of all fixed assets and conscientious management for efficiency and quality are necessary. These measures, combined with the closing of the least efficient small-scale enterprises, the development of light rather than heavy industry, and the relocation of energy-intensive industries, could eventually cut current energy use by one-third.

Further planned increases in coal production will require considerable capital and operational costs, technical expertise, and diligent management. Two-thirds of the increase is expected to come from new collieries, one-third of which will be large opencast mines. Much of the required increment must come from inefficient, labour-intensive, locally run mines that produce inferior fuel. This suggests that the emphasis is being placed on quantity rather than quality of fuel. The problems to be faced include air pollution, pipeline and rail

transportation obstacles, and difficulties in attracting foreign investment in the current market.

Offshore hydrocarbons may contribute to modernization, but there are many obstacles in addition to the challenge of locating oil and gas. These obstacles include a global market with huge reserves and falling real prices, stagnating demand for oil in the West, an inadequate infrastructure for delivery of gas, inadequate supply bases, and the lack of local expertise in the industry.

It is questionable whether China can reach its goal for electricity production given its technological and economic shortcomings. The expansion strategy is based on the construction of large-scale hydroelectric stations and of large stations at the mouth of coal mines. Because hydroelectric and coal production is not expected to be sufficient, a strong commitment has been made to nuclear generation.

The environmental considerations of increasing electricity production are significant. For hydroelectric generation, these include the threats to power supplies that are posed by recurring drought (exacerbated by deforestation) and the impact of the flooding of alluvial fields, which takes land out of production and dislocates tens of thousands of people. Shortages of water in the north will make it difficult to locate coal-fired thermal stations near the coal resources to reduce transportation problems. Although new plants are being equipped with electrostatic precipitators to remove particulate matter, no sulfur dioxide controls are planned. The increase in coal combustion will contribute to problems of air quality and acidification. Because nuclear power plants are planned for heavily populated areas, accidents will have serious consequences.

Even if the coal, oil, and electricity goals are achieved, energy supplies to the country's rural villages will not be improved greatly. Extensive efforts are required to develop and diffuse better stoves, plant fast-growing trees, construct small hydroelectric stations, and produce good-quality biogas digesters.

## **Conclusions**

China's poor use of its rich energy resources provides a huge potential for improvements and conservation to drive its modernization.

The planned increase in coal output and the quadrupling of electricity production will be difficult to achieve. Although the outlook for oil and gas is good, conversion to coal and maximum conservation of oil should continue. The accelerated construction of hydroelectric stations is rational, but plans for nuclear power stations in densely populated coastal regions are questionable. In addition, the country must aggressively expand rural energy without further degrading the environment. Successes and failures have characterized the past 35 years in China. Quadrupling of the economy within one generation presents enormous challenges.

# Energy in Latin America

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*Volume editor: Carlos E. Suárez*

# **Latin America: The Effects of Policy on Energy Resources, Transitions, and Alternatives**

*Adriana N. Bianchi*

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## **Overview**

This paper uses national, subregional, and regional examples to review energy policies and issues in Latin America from the onset of the energy crisis to the early 1980s. Practically none of the countries had an overall, coherent energy policy to ease them through this transition. The distribution of Latin America's energy resources, production capabilities, consumption patterns, and projected needs are analyzed to identify the problems and policies related to energy. Solutions to the most important problems are suggested, and priority areas for research are defined.

## **Analysis**

### **Energy Resources, Production, and Consumption**

In Latin America, energy resources are spread inequitably but include 11.6% of the world's crude oil, 6.2% of the world's natural gas, 1.73% of the world's coal, about 20% of global hydroelectric power, and unquantified potential in biomass, solar, wind, geothermal, and nuclear power.

Coal has not been seriously exploited in Latin America, and most of the remaining reserves contain high levels of impurities. About 8% of Latin America's potential hydroelectric reserves have been used. Hydroelectricity is the most important energy resource in the region. Regional expertise to plan, design, and construct hydroelectric power stations should ensure good development prospects. The region has sufficient installed capacity to manufacture some of the machinery and materials required for hydroelectric projects.

Biomass fuel is largely fuelwood that is used for heat in the residential, industrial, and transportation sectors and sugarcane (bagasse) that is used in the sugar industry.

Geothermal resources, which are abundant in Chile, El Salvador, and Mexico, are generally harnessed to generate electricity. There is a serious lack of data on the potential for the development of geothermal energy, but it might play a vital role in some countries.

Nuclear reactors generate some electricity, but all nuclear projects have suffered during the financial crisis, which has prolonged construction and forced a reassessment of the nuclear program. Nuclear energy will not play a significant role in Latin America in the short term.

Solar water heaters are widely used, and solar energy is being substituted for a considerable amount of electricity. A solar-intensity map is being drafted. Windmills are used to pump water, and the production of a wind-velocity map is planned. Some countries are trying to integrate solar and wind energy into their national energy sectors. Research on the transfer and adaptation of technologies is leading slowly to the establishment of commercial centres for the production of equipment and machinery to harness wind and solar energy. These sources will not be a key factor in the production of renewable energy in Latin America in the near future.

Latin American production of commercial energy has increased as a result of the discovery of new oil resources in Mexico in the 1970s. The production of primary energy has remained at fairly stable proportions (oil 70%, gas 15.6%, hydroelectric energy 11.4%, coal 2.9%, and geothermal and nuclear power combined at 0.1%).



Fuel consumption in the industrial sector is diversified. Coal and coke, biomass, oil derivatives, and electricity are all consumed in significant quantities. This diversification provides opportunities for conservation and substitution. An increase in energy consumption in the transportation sector reflects urbanization, economic expansion, and growth of the middle class. The transportation sector uses 4 of every 7 barrels (1 barrel = 0.16 m<sup>3</sup>) of oil consumed in the region and relies almost exclusively on this energy source.

The industrial sector is the major consumer of commercial energy, which reflects the growing importance of industry in the economy. Because of increased urbanization, the transportation sector displaced the residential-commercial sector as the major energy consumer, whereas the agricultural sector used little of the energy, which reflects its limited use of technology.

Alcohol is the only major nonhydrocarbon fuel used in the transportation sector, and its use is almost exclusive to Brazil. Energy use in the transportation sector, which has high levels of inefficiency and demand, could be greatly reduced by rationing.

OLADE (Organización Latinoamericana de Energía) has made projections of the supply and demand for energy. OLADE estimated that Brazil, Mexico, and the southern and Andean countries will require more than 94% of the region's energy by the end of the century. Because of efficiency gains, supply is expected to increase at an annual rate of 4.8%. High growth in the demand for hydrocarbons in some sectors (for example, transportation) and the lack of proven reserves in Central America make this subregion vulnerable to oil and gas shortages. Other subregions are less vulnerable because they have access to reserves or have policies that reduce their dependency on imported oil, exploit hydroelectric resources, increase energy efficiency, and intensify the use of bioenergy in industry.

## **Problems and Policies**

The region has faced severe economic stress in the past two decades. Opinion is mixed, however, on what effect steeply increasing petroleum prices had in relation to other global factors (for example, general inflation and the structure of the productive sectors).

A direct result of rising costs for petroleum products was an increase in demand for biomass. Attendant problems were the use of animal and plant wastes as cooking fuel instead of fertilizer and declines in forests. Most Latin American families (60–80%) use firewood and charcoal to cook food and to meet domestic energy requirements. The increase in the use of firewood has contributed greatly to environmental degradation. Current levels of deforestation endanger the rural environment, hydrographic conditions, and soils. They also affect hydroelectric potential and agricultural production. The replacement of fuelwood in the short term would require the rapid development of a distribution network for affordable alternative fuels. This task is highly improbable given the immense changes that would be required in the domestic and industrial infrastructure. If governments do not regulate their forestry reserves, most of the continent will be completely deforested in 20–30 years. Often the demand for land (rather than for timber or fuelwood) is the driving force behind deforestation. Some of the wood wasted in these clearing operations could be made into charcoal in portable kilns. Simple, inexpensive wood-burning stoves are available, but rural and low-income families are not convinced of their benefits or of the need to conserve fuel.

The responses of the different countries to these problems have varied from fuelwood enhancement to an emphasis on alternative fuels (for example, hydroelectricity and alcohol). The success of these responses must be qualified. Fuelwood programs are often too small to be significant or are uncoordinated. Alternative fuel programs often lack capital or face other fiscal constraints.

## **Energy Transitions**

An energy “transition” is defined as an effort by a country to move away from dependence on imported petroleum as its principal energy source. Countries have explored for domestic oil and nationalized energy industries. However, conservation, particularly in the industrial sector, has also had a noticeable impact on this transition. Increased fuel prices were a major conservation incentive. Conservation measures include the replacement and modification of indus-

trial equipment, improved use of the distribution system for electricity to reduce transmission losses, and increased efficiencies in the transportation sector (for example, new tires, diesel engines, and reduced speed limits).

It may be technically possible to replace imported oil with an indigenous energy source, but the economic and social implications are not always known. The transportation sector presents the greatest challenge for substitution because it uses the largest amount of imported oil and also serves all productive enterprises. Brazil's national alcohol program is a substitution success story. The program incorporates a number of social objectives but has social and economic shortcomings. The debate focuses on competing institutional interests, progress toward production goals, and consumer response, but there is little questioning of the rationale for substituting alcohol for gasoline.

Latin America possesses large quantities of renewable energy resources that have been neglected in favour of petroleum products. These resources are distributed in a way that gives every country the potential to develop at least one cost-effective alternative to petroleum.

The absence of planning is a major drawback to the systematic development of hydroelectric energy. It is an economically feasible, nonpolluting, renewable resource that requires low maintenance and has a long life. It could provide jobs and stimulate the economy. However, its potential cannot be reached until all countries have good knowledge of possible sites and development costs. Small hydroelectric power stations, particularly in rural areas, yield significant improvements in the quality of human life.

Geothermal power resembles hydroelectric power in its capital structure, high initial investment, low operating costs, and no fuel requirement. System reliability is high because the low steam pressures necessitate a large number of small generating units. El Salvador produces one-third of its electricity from geothermal steam, and it is one of the few countries that can estimate the generating capacity of its geothermal resources.

Biogas is considered the nonconventional energy source with the greatest development prospects and the best long-term potential for growth. In addition to making contributions to agricultural production, biogas helps reduce deforestation because it can replace firewood. Biogas also reduces environmental problems because it recycles animal and vegetable wastes. Although the value of biogas has been proven in Latin America, many of the plants are idle because they lack support from both private enterprise and the government.

The use of nuclear power is limited because of high capital costs, international restrictions on fuel supply, and dependence on imported technology. Political and emotional opposition exists because of concerns about safety, security, and radioactive waste disposal.

### **Suggestions for Further Research**

Decisions on energy should be made within the context of a well-established energy policy. However, most Latin American countries do not have such a policy. Energy conservation characterized policy efforts in the 1970s. Energy policy must provide for sustainable energy systems and include provisions for the development of energy resources and for energy use. If the energy planning process is to lead to the design of comprehensive and appropriate energy policies, it must be implemented within the context of a multidisciplinary, socioeconomic development plan.

National governments must be familiar with their own energy resources, demands, and technologies before they embark on developing the regional energy sector. There must also be greater interaction between scientists, industrialists, technologists, and policymakers to increase scientific input into energy policymaking. Energy policy is not a substitute for market mechanisms; it is a complement. Policymakers must balance the conflict between long-term planning for energy projects and short-term political objectives.

Oil will continue to be the foremost source of energy in Latin America. Conservation and rationalization programs are only first steps in the transition, not changes in consumption patterns. Reduction of oil imports is the central objective.

Vigorous efforts should be made to exploit biomass resources, and a suitable distribution system for biomass products (especially charcoal) is needed. Massive forestry programs to produce energy, and which involve local communities in their planning and implementation, are required to avoid further deforestation. Properly designed technologies to convert biomass would reduce the economic and environmental costs of cooking and heating for both rural and urban dwellers.

Where sites are available, hydroelectricity should have the highest development priority. Because the main obstacle to hydroelectric development is financial, development should concentrate on small power stations for rural electrification. The interconnection between countries must be accelerated, and hydroelectric development must be coordinated internationally. Latin America also requires realistic transportation schemes that reflect real needs, not simply preferences, and are compatible with available resources.

Most Latin American nations have the technology, resources, and expertise that are required. What is lacking is the capital to support the massive programs needed to develop alternative and renewable energy sources. Latin America has surplus energy. It also has proven capacity to carry out energy projects and to provide capital goods and engineering services for different areas of the energy sector. However, the energy sector in the region continues to depend on external markets for supplies, services, and technologies. National governments should make concerted efforts to change these import-export patterns by promoting intraregional trade.

# **Energy Options in Central America: The Need for Policies**

*V. Susan Bogach*

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## **Overview**

Energy is a prime constraint to development in Central America, but it is not the most important constraint. Economic recession, political strife, and war, or the threat of war, are more fundamental problems. However, energy accounts for a large share of national import bills and investment programs. Regional analysis of the problems and options for energy in Central America is limited by political fragmentation. To meet future challenges in the energy sector, a planned, coordinated approach is required to address the energy options available in the region.

## **Analysis**

### **Energy Consumption Trends**

Just as there are two different spheres of economic activity (modern industry and agriculture, and small traditional industries and subsistence farmers), there are modern and traditional fuels. There is a strong pattern of overlap between activity and fuel. Modern fuels tend to serve industries and large agriculture, whereas traditional fuels serve the subsistence economy. Development planners tend to consider these spheres as separate, and they ignore areas of overlap (for example, transportation and agriculture). A large share of non-

commercial fuel is marketed in urban centres, whereas rural people are strongly affected by the availability and price of petroleum products, mainly because of their dependence on the transportation system.

Consumption of modern fuels varies widely and follows economic trends. Petroleum consumption has decreased dramatically because of falling production, large increases in the price of gasoline, curtailment of travel in countries with guerrilla warfare, and rationing in Nicaragua. The share of electricity as a modern fuel is increasing, but supply is limited in many countries and there is unsatisfied demand from potential customers who are waiting to be connected to the grid.

Among the traditional fuels, wood is, and will continue to be, the most important indigenous energy source. Traditional fuels are used for domestic cooking, in traditional industries, and in commercial enterprises. Agricultural residues supplement wood on a seasonal basis. Bagasse is used extensively in sugar processing. Although data are lacking for traditional fuels, it is known that the commercial trade in wood is large and occurs mainly in urban areas, charcoal consumption is minimal, industries are switching from modern fuels to wood when the price of wood is competitive, there have been sharp increases in the price of wood in recent years, and there is a trend to maximize the use of bagasse and wood in sugar processing and to minimize the use of diesel.

The rapid increase in modern energy requirements from 1970 to 1978 was caused by population growth, a healthy rate of economic expansion, and rapid urbanization. Forecasts of modern energy requirements were based on positive assumptions and overestimated demand in the early 1980s. Because there is no accurate information on present trends in the use of traditional energy, forecasts are difficult. However, there is a steady increase in the consumption of fuelwood because of rapid population growth and high costs of other forms of energy.

Because of the uncertain political and economic stability of the region, it is almost impossible to forecast economic development and

related energy demand. However, it is expected that energy growth will be slow because of limited economic growth.

## **Supply and Resources**

Petroleum and wood dominate energy supply. Oil is the most widely used form of modern energy, but its share is slipping as hydroelectric and geothermal power replaces petroleum in electricity generation. Exploration has been minimal because of the political situation and because the oil industry has limited geological interest in Central and South America.

Central American countries benefit from an annual agreement with Mexico and Venezuela that involves a low-interest line of credit equivalent to 20% of the purchase price of reconstituted crude. Interest on this line of credit is reduced further if the funds are used for development projects. However, the nature of the reconstituted crude oil that is supplied does not match customer demand. Each country has its own refinery, which is small, uneconomical, and running below capacity. Imports make up the shortfall in light oil products.

Hydroelectric power has always played an important role in Central America. Steep terrain and heavy rainfall mean that hydroelectric resources can supply the majority of the region's electricity until the year 2000. Geothermal resources are relatively unknown, but El Salvador has advanced the farthest in developing geothermal potential. Coal is not produced in Central America, and deposits are mainly low-quality subbituminous coal.

Wood production, conversion, and use are labour intensive and have low costs in foreign exchange. High oil prices have opened the door for new uses of wood fuels (firewood, charcoal, wood chips, pellets, and methanol). Wood consumption exceeds sustainable supply in the densely populated parts of Central America. Generally, the cutting of fuelwood contributes to the negative effects of deforestation only after the land has been cleared for other purposes (for example, agriculture).

Other indigenous resources contribute to the region's supply base. Bagasse supplies most of the heat, steam, and electricity re-



quired for sugar processing. There is no incentive for efficient use of bagasse because the fuel is free. If the excess power could be sold to utilities, sugar processors might use bagasse more efficiently. Little is known about the amount of solar energy used for product drying on a commercial or household scale, but subsistence farmers have always dried their crops in the sun. Solar heat will play a larger role in the future.

Animal power is of limited importance in Central America because the steep slopes must be cultivated by hand. Wind-driven water pumps are used in some parts of Central America. Biogas production from animal manure and agricultural wastes occurs on a small scale on dairy and swine farms, but the average family does not own enough animals to generate the necessary wastes. Alcohol production has been considered, but a distillery in Costa Rica closed because of a lack of raw material.

## **Energy Problems**

A major issue is to reduce the foreign exchange costs of energy to enhance rather than constrain development. Some of the components of this problem include

- Strong and increasing dependence on imported petroleum,
- Fuelwood shortages or deficits,
- Inadequate institutional structures for energy management,
- Inefficiency of the energy infrastructure in the region,
- Increases in energy costs,
- Shortage of foreign exchange, and
- Economic and political uncertainty.

## **Energy Options**

Energy strategies to meet the problems of the region include three important options:

- Promote exploration and development of indigenous resources.
- Encourage fuel conservation and substitution.
- Improve the energy infrastructure.

## **Existing Energy Policies**

Many Central American countries have made progress in creating institutional structures to administer and manage their energy sectors. However, in most countries government decisions still reflect the preeminence of the national electricity companies.

Although little official policy exists, a review of government actions reflects policies to

- Develop hydroelectric and geothermal power to minimize the use of petroleum to generate electricity,
- Encourage petroleum exploration by making geological data available to companies and by changing petroleum legislation,
- Protect local refineries,
- Set petroleum prices at a level that covers costs,
- Shield the residential and transportation sectors from the full impact of increases in oil prices by using gasoline revenues to subsidize diesel, liquefied petroleum gas, and kerosene,
- Improve the energy database, and
- Ration (in Nicaragua) to restrain demand and the outflow of foreign exchange.

Central American countries must develop and adopt energy strategies. Direct government action is needed to create local initiatives.

## **Suggestions for Further Research**

Increase knowledge on the current energy system and the energy resource base by conducting research on

- Economic overlaps and energy flows between the traditional and modern sectors,
- The extent of energy resources (including wood and biomass),
- The dynamics of the commercial market for fuelwood and charcoal,
- The supply and use of bagasse, and

- The consumption, cost (in time or money), and availability of all fuels used in households, commercial enterprises, and industry.

Use research and demonstrations to define technological options for

- The production of fuelwood from fast-growing trees in small woodlots, commercial plantations, and agroforestry projects,
- The development of efficient equipment to use and convert wood (both in homes and in industry) and to use bagasse and agricultural residues in agricultural processing, and
- The production of liquid fuel from biomass.

Research is also needed on the role that the government should play in the energy sector. Practical research should explore

- Objectives of energy policy,
- Integration of energy planning with planning in other sectors,
- Institutional structures needed to manage the energy sector,
- Ways that the rate of resource development can be increased (especially for petroleum),
- Options for energy substitution and conservation (especially in industry and transportation) and for increasing the use of hydroelectricity,
- Methods to optimize the production and use of fuelwood and charcoal,
- Energy prices needed to meet policy objectives, and
- Methods to assess the impact of decisions on different sectors, social groups, and regions.

Links must also be established between research and implementation. Results should be published rapidly and diffused widely. Regional research projects should be encouraged to use the skilled individuals that are currently available.

# **A Triad-Based Energy Development Scheme: Application to Research and Development Projects in Costa Rica, Colombia, Venezuela, and Mexico**

*Gustavo Best*

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## **Overview**

The main energy goal of every Latin American country is to have enough energy available to fill its needs and allow for economic growth. Despite Latin America's current dependence on petroleum products, prospects of surviving the transition from oil to other energy sources are good because of the abundance and variety of energy resources in the region. An essential step in this transition is for each country to broaden its energy base to include whatever local resources (especially renewable resources) it can most easily exploit. The development of the energy sector should be guided by a national development program that determines the style of development and influences energy policies and energy demands.

## **Analysis**

### **Structure of the Triad-Based Energy Scheme**

The triad-based energy development scheme provides a theoretical framework in which to analyze each energy system. The analysis

looks at both the resource and its requirements and produces data in “couples” or “pairs” to reflect both supply and demand.

To define the potential of these pairs, the level of technical applicability of each pair must be analyzed. If the technology does not yet exist to exploit the “paired” research, development or demonstration of a certain type is required. If the technology exists, transfer, adaptation, or acquisition activities may be needed. If the technology is available but is not practical for use in the field, industrial and commercial infrastructure must be developed. All these activities require specific training and information. The result of this process is a series of “triads.” These triads include a pair (a resource and an end use) plus a technology that could be applied to that resource to achieve the end.

The most critical step is the evaluation of alternative triads. This evaluation should incorporate such key elements as financial conditions, price policies, and legislation and nontechnical barriers that are set forth in the national development program.

## **Country Studies**

Triad-based energy analyses were applied to Colombia, Costa Rica, Mexico, and Venezuela. In each country, the energy sector was reviewed within an analytic model that included an energy balance that compared supply–demand patterns to identify key relationships, a resource base that identified major indigenous energy resources, a human resource base that identified intellectual capabilities, and an institutional framework that identified institutions that could support triad-based energy analysis. Recommendations to enhance the R&D efforts in each country were developed from the analysis.

**Costa Rica** — Countries in Central America might address their energy problems as a region rather than as individual nations. Costa Rica is relatively advanced in institutional coordination in the energy sector and is able to link most of the required activities to implement energy options. The R&D efforts should

- Take advantage of the existing technical and institutional infrastructure by consolidating national working groups in specific applications or triads,
- Consider the economic implications of applications and take into account the possibility of regional markets,
- Link decentralized systems for electricity generation to the national network, and
- Assess the advantages of producing alcohol as an alternative to the conventional fuels used for transportation.

**Colombia** — Few R&D projects have contributed to the diversification and expansion of Colombia's energy base. The R&D efforts should

- Complement national priorities (for example, biogas for multiple uses, small hydroelectric power plants, wind for pumping, solar power for grain drying, and solar cells),
- Transfer technology to the final producer or consumer and create an infrastructure for diffusion,
- Provide training opportunities in technical and field implementation and define the role of energy as a tool for development,
- Develop methods to evaluate the technical and economic aspects of energy options, and
- Encourage multidisciplinary projects.

**Venezuela** — The effectiveness of R&D could be improved if efforts were made to

- Coordinate isolated research activities with a national program of energy options and incorporate renewable energy sources into national plans and policies,
- Consider the economic and sociocultural aspects of an application (including market evaluations, not just the technological aspects),
- Emphasize the development of solar cells made of amorphous silicon to ensure that Venezuela can acquire systems or establish facilities for local production,

- Evaluate the wind potential and design, test, and produce prototype wind systems,
- Incorporate wood residues from forestry activities and sugar-cane bagasse into the resource base for energy, and
- Identify priorities and concentrate resources and personnel to reduce one-person projects.

**Mexico** — To make research on energy for renewable resources more effective it is necessary to

- Evaluate renewable resources from an economic point of view (including demand and commercial feasibility) before they are incorporated into national energy plans,
- Better define the scope of R&D and include both long- and short-term objectives,
- Give priority to the development of rural energy and take sociological, cultural, and environmental issues into account,
- Develop projects to assess the possibility of substituting renewable energy for conventional sources (for example, oil), and
- Consider wood gasification, low-enthalpy geothermal processes, pyrolysis of urban residues, and solar techniques of food conservation in rural, agro-industrial, and peri-urban sectors.

### **Key Issues for R&D on Renewable Sources of Energy**

In most cases, Latin American countries are only evaluating conventional sources and hydroelectric energy. There are few centralized efforts to assess biomass, solar, wind, or other renewable energy sources. Academic institutions have assumed the major responsibility for R&D on renewable energy resources. The few isolated efforts to collect information on renewable energy resources yielded unreliable data because equipment was poorly maintained and calibrated and standard methods were not used.

Energy demand, the key factor in the planning of energy development, is a dynamic variable. The evaluation of demand requires a

political definition of the style of development. Research institutions should draw on economic, political, sociological, scientific, and technological expertise to study and analyze the actions and investments needed for different energy options.

The development of technologies for renewable energy has fallen traditionally into the purview of regional academic institutions. Unfortunately, few of these technologies have been incorporated into the national economy. One of the main problems facing Latin American researchers is selecting the most promising alternatives in energy technology and making the best use of limited financial, institutional, and human resources for their development.

A large number of R&D projects have fewer researchers than they require. At the same time, research efforts must avoid duplication of effort and budgets. Because many researchers have been trained abroad and have been funded to attend meetings, they have been able to develop natural and effective communication channels to keep in touch with scientific and technological developments elsewhere. Bilateral and multilateral cooperation must be continued and encouraged.

The industrialization and commercialization of technologies for renewable energy pose a special problem in Latin America because almost no industrial infrastructure exists in the field of renewable energy resources. The market that exists is served by small companies that have almost no contact with the government agencies that determine the policies and prices. These two sectors must be brought closer together.



# **Energy Policy in Latin America: A Break with the Past**

*Miguel S. Wionczek*

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## **Overview**

Research within the “Programa de Energeticos” has addressed the past, present, and future energy problems of Mexico. As well, it has examined Latin American and global energy issues. Worldwide contacts provide a global perspective on the energy problems of developing countries. Latin America’s seemingly poor endowment of oil, gas, coal, and uranium reflects its technological shortcomings rather than a lack of resources. A clear understanding of Latin America’s present and medium-term energy potential is vital if a meaningful energy strategy is to be formulated. The management and uses of renewable energy only reflect the prevailing style of development; they are not instruments for change. Latin Americans cannot expect to formulate logical energy policies if they have virtually no understanding of either the extent of their own resources or contemporary developments in the global energy sector. The transition from hydrocarbons to other energy sources is likely to take more than a century, not 25–30 years.

## **Analysis**

Latin American energy policy is based on assumptions that are no longer valid. Nations continue to be classified as “oil rich” and “oil

poor," and frantic pleas are made to begin substituting renewable resources for hydrocarbons.

Energy reserves are nothing more than a convenient term to express what is known about a country's energy supply. A reserve is a broad approximation. It is the amount of oil that experts suspect is available for exploitation at prevailing prices with the existing technology and within the legal systems in force. Nontechnical factors (for example, the tendency of hydrocarbon producers to adopt conservative attitudes toward reserves and to manipulate the data on reserves and resources for the purposes of energy marketing) add additional cause for caution. This pessimistic approach is reinforced by nationalistic attitudes that view energy problems and solutions as country-specific.

The oil industry has thoroughly explored and developed only a limited number of areas of the world. Latin America, Africa, and Southeast Asia contain almost 50% of the world's potential hydrocarbon reserves, but exploration in these areas has been minimal. The willingness of Latin America to trust data produced and provided by multinational oil companies and by government agencies in industrialized countries represents an almost insurmountable obstacle to energy planning and policymaking. However, exploration in oil-rich Latin American nations offers evidence that there is much more oil and natural gas.

In 1982, data presented at an international meeting suggested that Latin America was an area that produced almost no natural gas. However, a survey of the reserves and production of natural gas in Latin America by the Programa de Energeticos strongly suggested that resources in 10 major countries in Latin America were many times the figures circulated among energy experts. Large reserves of natural gas have been discovered in Latin America, and there is also a clear trend toward substituting natural gas for oil and other conventional energy sources. Because many countries also have oil reserves that were not suspected earlier, the role of nonconventional and renewable energy sources should be reexamined.

Close connections and communications between energy researchers and energy policymakers must be developed. It is difficult

to organize energy research because of overspecialization, financial and institutional constraints, and a lack of clear priorities. These factors result in energy research that is random, follows ideological preferences, and is undertaken by small, like-minded groups of people. This type of research may be marginally useful at the country level, but the combined findings are unlikely to be useful for regional energy planning.

Latin America's unsatisfactory planning efforts are made worse by a lack of input from R&D projects. Policymakers take little account of R&D, and this is reflected in weak support for research activities. Few countries in the region have the necessary expertise at the national level to conduct, finance, diffuse, and use energy research.

Latin America's patterns of energy consumption are a legacy from the industrial world and are reinforced by the operations of the international oil industry. If it is assumed (it has not been proven) that Latin Americans are poor in nonrenewable energy, a greater use of renewable sources would not necessarily result in a new style of development that would lead to more equitable social and economic conditions. There is no intrinsic link between patterns of energy use and styles of development that would guarantee this outcome. Energy sources are neutral. It is the structure of the economy and society that determines who can consume the available energy. The social structure must be changed to improve both the supply and the use of energy.

Three lessons can be drawn from the analysis of the links between energy problems and equitable development. First, the conventional view is that present energy resources are mismatched with their current uses and future energy needs. However, it is a fallacy that something urgent must be done to diversify energy supplies (with a particular emphasis on renewable sources). Second, there is a need to make explicit the link between energy and socioeconomic development. Third, the lack of cooperation between researchers and policymakers weakens both research and policy.

Research designs reflect antiquated notions of the energy situation in Latin America. Little research is being done on the economic

and social costs and benefits of newly proposed energy strategies. Latin America shows little, if any, spirit of innovation in the design of its energy policies; therefore, the policies become nothing more than a response to outside financial pressures.

## **Suggestions for Further Research**

The issues that require urgent attention from researchers and policy-makers in Latin America are

- The true extent of major energy resources in the region and in individual countries,
- The external constraints on the development of these resources (particularly the financial and other policies of the World Bank, the International Monetary Fund, and other international agencies dominated by industrialized countries),
- Detailed outlines, supported by analytic and technical exercises, of energy strategies for the region and the subregions that take account of available energy resources and worldwide technological advances,
- Studies of the social costs and benefits of alternative energy mixes at the national level (based on the assumptions that Latin America is not about to run out of hydrocarbons and that the transition from oil to as yet unidentified energy sources will last much longer than previously assumed),
- Real prospects for regional energy cooperation,
- Links, if any, between patterns of energy use and development style,
- The nature of the obstacles to meaningful dialogue between energy researchers and policymakers and the reasons for the sad and counterproductive state of affairs,
- Problems arising from the introduction of nuclear energy into Latin America (particularly the deceit and fraud practiced by producers of nuclear energy equipment and by the “nuclear lobbies”),

- The conditions that limit the use of “exotic” sources of renewable energy in subsistence agriculture,
- Ways to consolidate a “critical mass” of energy researchers at the national and subregional levels, and
- The limitations imposed on energy research in Latin America by the international economic crisis.

## **Acronyms and Abbreviations**

AC	alternating current
ARI	accute respiratory infections
BaP	benzo[a]pyrene
BHEL	Bharat Heavy Electricals Limited
BWR	boiling water reactor
CANDU	Canadian deuterium uranium
CFRI	Central Fuel Research Institute
CMRS	Central Mining Research Station
CNG	compressed natural gas
CRF	capital recovery factor
DC	direct current
EBT	energy balance table
EDA	energy demand analysis
EDM	energy demand management
EHV	extra-high voltage
EIM	energy-intensive material
EMF	Energy Modeling Forum
EOR	enhanced oil recovery
ERG	Energy Research Group
ESDM	energy supply and demand management
ESM	energy supply management

FAO	Food and Agriculture Organization of the United Nations
FBR	fast breeder reactor
FTE	freight transport energy
GDP	gross domestic product
GNP	gross national product
HVDC	high-voltage direct current
IBRD	International Bank for Reconstruction and Development (World Bank)
IIASA	International Institute of Applied Systems Analysis
IIP	Indian Institute of Petroleum
IMF	International Monetary Fund
INEP	integrated national energy planning
IO	input–output
IRR	internal rate of return
IRS	Institute of Reservoir Studies
LDC	less developed country
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LRMC	long-run marginal cost
LWR	light water reactor
MEDEE	Modèle d'évolution de la demande d'énergie
MIGA	Multilateral Investment Guarantee Agency
MSEDm	Minimum Standard Energy Demand Model
MSY	maximum sustainable yield
MTBE	methyl tertiary butyl ether
NGO	nongovernmental organization
NPV	net present value
NSSS	nuclear steam supply system

OECD	Organisation for Economic Co-operation and Development
OIDCs	oil-importing developing countries
OLADE	Organizacion Latinoamericano de Energia
OPEC	Organization of Petroleum Exporting Countries
PAH	polycyclic aromatic hydrocarbon
PCF	plant capacity factors
PRC	People's Republic of China
PTE	passenger transport energy
PV	present discounted value
PVC	present value of total costs
PWR	pressurized water reactor
R&D	research and development
RAPAD	Research Association for Petroleum Alternatives Development
RES	reference energy system
RWS	rated wind speed
SCADA	system control and data acquisition
SCP	single-cell proteins
SIMA	Simulation of Macroeconomic Scenarios to Assess Energy Demand
SIPH	solar industrial process heat
SRMC	short-run marginal cost
TSP	total suspended particulates
UHV	ultra-high voltage
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organization
USAID	United States Agency for International Development



WAES	Workshop on Alternative Energy Systems
WASP	Wein Automatic System Planning Package
WEC	World Energy Conference

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*Energy Research in Developing Countries* summarizes the 14-volume Energy Research Group (ERG) series, which is copublished by IDRC, the United Nations University, and Wiley Eastern Ltd (India). The series discusses energy technologies and options, and provides a solid knowledge base for making decisions about effective approaches to energy and development. The wide range of topics include bioenergy, industrial energy use, and how developing countries are satisfying energy demand.

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